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Lars-Åke Claesson, Mirab Mineral Resurser AB

Göran Nilsson, Anders Ullberg
GNC AB

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Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co
Box 5864
SE-102 40 Stockholm Sweden
Tel 08-459 84 00
+46 8 459 84 00
Fax 08-661 57 19
+46 8 661 57 19

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Keywords: AP PF 400-05-003, AP PF 400-05-123, Core drilling, Overcoring, Drill site DS7.

Abstract

The major part of the deep boreholes drilled within the scope of the Forsmark site investigations are performed as telescopic boreholes, entailing that no drill core is received from the upper 100 metres. To compensate for this deficiency, a conventional core drilled borehole to 100 metres is normally drilled.

At drill site DS7 within the Forsmark investigation area, a 1,000 m deep telescopic borehole, KFM07A, was initially drilled, indicating low-fractured and low-conductive rock at depth, whereas the shallow parts were fractured and to some extent highly water-yielding. In the course of the site investigations a decision was made to drill a traditional cored borehole, i.e. with retrieval of drill core all the way from rock surface, in order also to permit rock stress determinations by overcoring measurements down to repository depth. This borehole would also provide a drill core all the way from the rock surface.

This borehole, which is denominated KFM07B, is 298.93 m long, inclined 53.71° from the horizon, and reaches about 233 m in vertical distance from the ground surface. The upper part to 65.69 m was core drilled with 96 mm diameter, and was cased with a stainless steel casing, whereas the lower part was core drilled with the diameter 76 mm. The gap between the borehole wall and the casing was grouted.

Already from the beginning of the rock stress measurement programme, difficulties to obtain an efficient cleaning in the pilot borehole resulted in irregular gluing of the strain gauges towards the pilot borehole wall, a problem which often resulted in disturbed measurements. Part of the problem was suggested to be due to the large inclination of the borehole, which resulted in a band of drilling debris settled on the lower borehole wall, and it turned out to be very difficult to clean the borehole wall from this material. Another cause of the problem was occurrence of shallow fractures, into which much of the flushing water discharged, hence reducing the amount of water available for cleaning the borehole from drill cuttings. To seal the shallow water inflow, two grouting attempts in section 81–208 m were performed. Furthermore, as the borehole showed a tendency of deviating upwards, thereby increasing the inclination still more, guided drilling in six sections between 166–208 m was performed, a measure which steered the borehole back to the original starting inclination value.

In spite of all efforts that were made, the efforts to attain acceptable stress measurements with the overcoring technique were not successful, and therefore the borehole was completed at 298.93 m. A conclusion that may be drawn is that inclined, conventional boreholes are not optimal for conducting rock stress measurements with over coring technique.

To fulfil the rock stress programme, another borehole, which is denominated KFM07C, was drilled. In this case the borehole design chosen was a steep (inclined 85.40° from the horizon), telescopic drilled borehole. KFM07C was drilled to 500.34 m and reaches about 495 m in vertical distance from the ground surface. The percussion drilled section 0–85 m was cased with a stainless steel casing, and the gap between the borehole wall and the casing was grouted. These measures entailed that all inflow of groundwater to the percussion drilled part of the borehole ceased.

The chosen technique with a steep borehole, which more efficiently prevents drill cuttings from adhereing to the borehole wall, combined with telescopic drilling, which permits continuous pumping in the upper part of the borehole, thereby increasing the retrieval of drill cuttings, appeared to be much more suitable for performance of overcoring stress measurement than the conventional cored borehole. The favourable borehole design was combined with a newly developed system for nitrogen flushing, where the lower end of the gas tubing was placed inside the pilot hole. These measures together improved the cleaning of the pilot borehole, resulting in better gluing and thus more solid data colleting. Measurements were performed at six levels. However, towards depth, where the stress level at Forsmark is increased, tendencies of microfracturing and core discing were observed.

A sampling- and measurement programme for core drilling provided preliminary information about the geological and hydraulic character of the borehole directly on-site. It also served as a basis for extended post-drilling analyses. E.g. the drill cores together with later produced video images of the borehole wall (so called BIPS-images), were used as a basis for borehole mapping (so called Boremap mapping) performed after drilling. Results of the Boremap mapping of KFM07B and KFM07C are presented in this report.

After completed drilling, grooves were milled into the borehole wall at certain intervals as an aid for length calibration when performing different kinds of borehole measurements after drilling.

By the drilling of KFM07B and KFM07C, although some major measurement problems encountered, a better characterization of the Forsmark rock stress field was achieved. Boreholes KFM07A and KFM07C were later used for rock stress measurements by hydraulic technique, which further improved the characterization of the stress field in connection with drill site DS7. Besides, the three boreholes at the drill site together have provided a basis for a good characterization of the geological, hydrogeological and hydrochemical characteristics of an interesting part of the Forsmark candidate area.

Sammanfattning

De flesta djupa (0–1 000 m) borrhål inom Forsmarks platsundersökning utförs som teleskopborrhål, varför borrkärna saknas mellan 0–100 m. För att kompensera för den uteblivna borrkärnan i övre delen borras vanligen ett konventionellt kärnborrhål till 100 m.

På borrplats BP7 i Forsmarks undersökningsområde finns ett 1 000 m djupt teleskopborrhål, KFM07A. Borrhålet uppvisade vid borrningen ett sprickfattigt och lågkonduktivt berg mot djupet, medan de övre partierna hade förhöjd sprickfrekvens och i vissa sektioner hög vattenföring. Under platsundersökningens gång beslutades att ett traditionellt kärnborrhål skulle borras för att möjliggöra bergspänningsmätningar med överborrningsmetoden ner till förvarsdjup. Detta borrhål skulle också ge borrkärna hela vägen från bergytan.

Borrhålet, som benämns KFM07B, blev 298,93 m långt, är ansatt med 53,71° lutning från horisontalplanet, och når cirka 233 m vertikalt. Den övre delen av borrhålet kärnborrades med dimension 96 mm till 65,69 m och kläddes in med ett rostfritt foderrör. Slutligen cementinjekterades spalten mellan borrhålsvägg och foderrör så att fullgod täthet uppnåddes.

Redan när bergspänningsmätningarna inleddes konstaterades stora svårigheter att få fullgod limning av mätcellens trådtöjningsgivare i pilotborrhålet. Problemet bedömdes orsakas av två faktorer. Borrhålets flackhet förorsakade att en sträng med borrkax blev liggande på den nedre borrhålsväggen. Det visade sig mycket svårt att med spolning rengöra borrhålsväggen tillräckligt mycket för att goda limningar skulle uppnås. Den andra problemfaktorn var förekomst av ytliga, konduktiva sprickor, i vilka en stor del av spolvattnet dränerades bort. Därmed försvårades möjligheterna att med vattenspolning rengöra borrhålets djupare delar.

För att avtäta inflödena i borrhålet utfördes två injekteringar ner till 208 m. Eftersom borrhålet dessutom visade en tendens att kröka uppåt, så att det blev ännu flackare, utfördes ”styrd borrning” i sex sektioner mellan 166–208 m, vilket återställde inklinationen till startvärdet. Trots dessa insatser var det inte möjligt att rengöra pilotborrhålet så mycket som behövdes för att trådtöjingsgivarna skulle kunna limmas tillräckligt bra. Efter ett 20-tal mätförsök avbröts borrningen i förtid vid 298,93 m.

Istället borrades nu ett teleskopborrhål som benämns KFM07C. Detta borrhål, som är ansatt med 85,40° lutning från horisontalplanet, blev 500,34 m långt och når cirka 495 m vertikalt. KFM07C hammarborrades i avsnittet 0–85 m och kläddes in med ett rostfritt foderrör som cementinjekterades i spalten mellan borrhålsvägg och foderrör, så att vatteninflödet i den hammarborrade delen av teleskopborrhålet upphörde.

Det nu valda borrhålsutförandet med ett brant borrhål borrat med teleskopteknik, vilket dels försvårar för borrkax att fästa vid borrhålsväggen, dels möjliggör kontinuerlig pumpning av borrhålet under borrning och därmed ökad uppfordring av borrkax, visade sig avsevärt förbättra möjligheterna att utföra bergspänningsmätningar med överborrningsteknik. Detta kombinerades med introduktionen av en nykonstruerad utrustning för kvävgasblåsning av borrhålet, där gasslangens nedre ände placerades i pilotborrhålet, vilket ytterligare förbättrade rengöringskapaciteten. Med dessa åtgärder kunde pilotborrhålet rengöras i sådan grad att limningen av trådtöjningsgivarna blev så bra att tillfredsställande mätresultat erhölls. Mätningarna utfördes på sex nivåer. Mot djupet, där spänningsnivåerna är förhöjda, observerades dock tendenser till mikrouppsprickning och core discing, varför mätningarna avslutades vid 426 m.

Ett mät- och provtagningsprogram för kärnborrningen gav preliminär information om borrhålens geologiska och hydrauliska karaktär direkt under pågående borrning samt underlag för fördjupade analyser efter borrning. Bland de insamlade proverna utgör borrkärnorna tillsammans med videofilm av borrhålsväggen (s k BIPS-bilder), arbetsmaterialet för den borrhålskartering (s k Boremapkartering) som utförs efter borrning. Även resultaten från Boremapkarteringen av KFM07B och KFM07C finns redovisad i föreliggande rapport.

Efter avslutad borrning frästes referensspår in i borrhålsväggen med syftet att användas för längdkalibrering i samband med olika typer av borrhålsmätningar som senare utförs i det färdiga borrhålet.

Genom borrning och bergspänningsmätningar i borrhålen KFM07B och KFM07C kunde kunskapen om spänningsfältet i Forsmark förbättras, trots de mätproblem som beskrivits ovan. Borrhålen KFM07A och KFM07C användes senare för bergspänningsmätningar med hydraulisk metod, vilket ytterligare fördjupade kunskaperna om spänningsfältet i anslutning till borrplats BP7. Dessutom har borrningen av de tre kärnborrhålen KFM07A, B och C medfört att de geologiska, hydrogeologiska och hydrokemiska förhållandena i denna intressanta del av Forsmarks kandidatområde kunnat beskrivas på ett bra sätt.

Contents

1 Introduction

This document reports the performance of and results gained by core drilling of boreholes KFM07B and KFM07C, which are two of the activities performed within the site investigation at Forsmark. The work was carried out in accordance with activity plans AP PF 400-05-003 and AP PF 400-05-123. In Table 1-1 controlling documents for performing this activity are listed. Both activity plans and method descriptions are SKB's internal controlling documents. The method descriptions are referring to a number of method instructions also mentioned in the text of this report.

Drilling is one important activity within the scope of the site investigations. Three main types of boreholes are produced: core drilled respectively percussion drilled boreholes in solid rock and short boreholes drilled through regolith. The last type may be accomplished by different drilling techniques, e.g. percussion drilling and auger drilling.

The deepest boreholes drilled at the site investigation are core drilled boreholes in hard rock. During the site investigation three sub-vertical and ten inclined, approximately 800–1,000 m long, cored boreholes have been drilled within the investigation area. Besides, seven semi-deep boreholes and five short boreholes have also been core drilled. The locations of the twelve drill sites in question, DS1 to DS12 are illustrated in Figure 1-1.

By drilling the deeper and semi-deep boreholes, a so called telescopic drilling technique is applied, entailing that the upper part, normally maximum 50–100 m, of the borehole is percussion drilled with a large diameter (≥ 200 mm), whereas the borehole interval below is core drilled with a diameter of approximately 76–77 mm.

In order to compensate for the missing core in the percussion drilled part, a shorter conventional core borehole might be drilled nearby, in which drill core is retrieved all the way from the rock surface.

For the study of the rock stress field at Forsmark, two semi deep boreholes called KFM07B and KFM07C were drilled between May 30th and October 18th, 2005, (KFM07B) and between December 20th, 2005, and August 8th, 2006, (KFM07C) from drill site DS7. These boreholes were drilled to 298.93 m (KFM07B) and 500.34 m (KFM07C) lengths respectively. Previously, a telescopic borehole, KFM07A, was drilled from the same drill site to 1,001.55 m length /1/. Borehole KFM07B is a conventional core drilled borehole, which hence also compensates for the missing drillcore in borehole section 0–100 m in KFM07A. Borehole KFM07C is, like KFM07A, a telescopic borehole.

Table 1-1. Controlling documents for performance of the activity.

Activity plan	Number	Version
Kärnborrning och bergspänningsmätningar i KFM07B.	AP PF 400-05-003	1.0
Teleskopborrning av och bergspänningsmätningar i borrhål KFM07C.	AP PF 400-05-123	1.0
Method descriptions	**Number**	**Version**
Metodbeskrivning för kärnborrning.	SKB MD 620.003	1.0
Metodbeskrivning för hammarborrning.	SKB MD 610.003	2.0
Metodbeskrivning för genomförande av hydrauliska enhålspumptester.	SKB MD 321.003	1.0
Metodbeskrivning för registrering och provtagning av spolvattenparametrar samt borrkax under kärnborrning.	SKB MD 640.001	1.0
Metodbeskrivning för pumptest, tryckmätning och vattenprovtagning i samband med wireline-borrning.	SKB MD 321.002	1.0
Method description for in situ stress measurements by means of overcoring using the *Borre* probe.	SKB MD 181.001	1.0

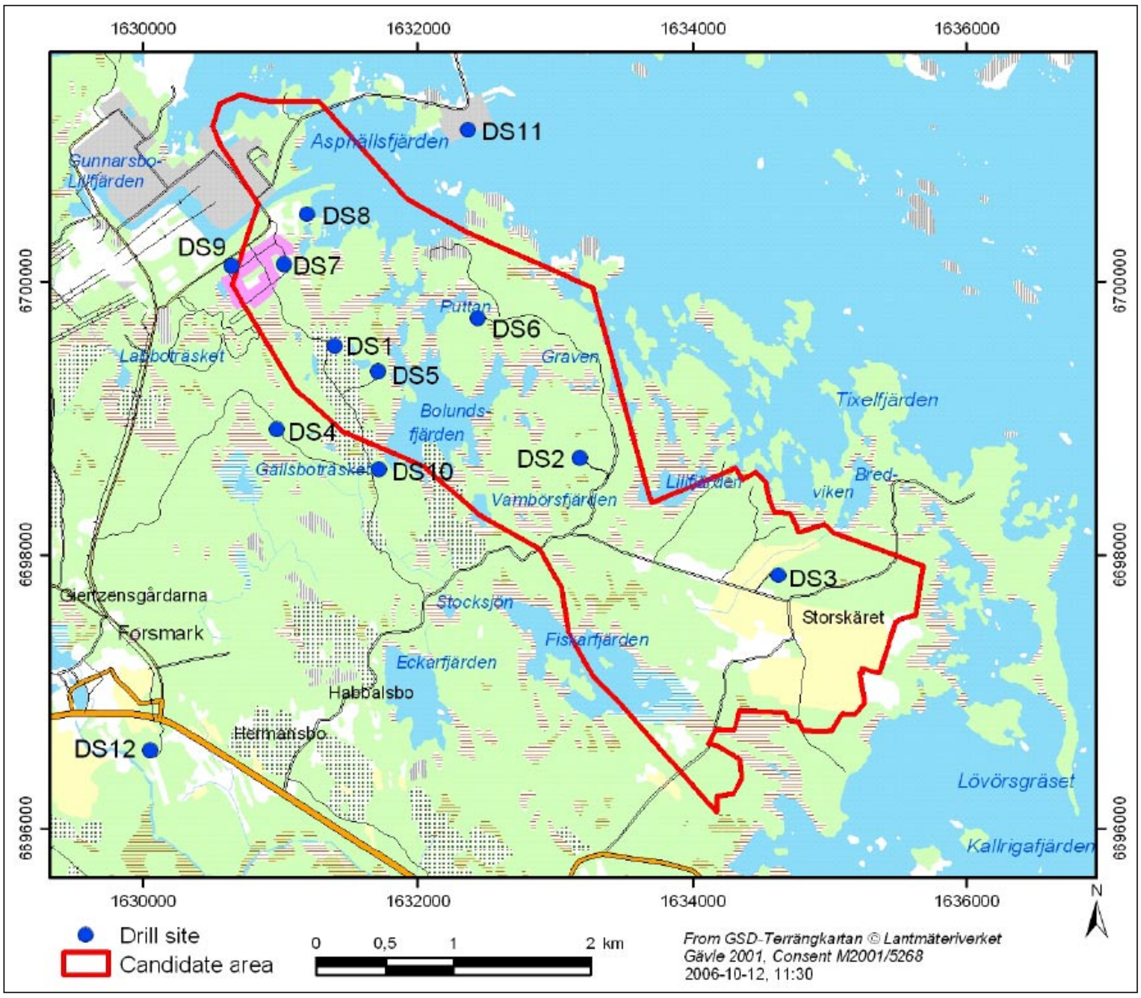


__Figure 1-1.__ The site investigation area at Forsmark including the candidate area selected for more detailed investigations. Drill sites DS1-12 are marked with blue dots.

Close to the three core drilled boreholes at drill site DS7, also percussion drilled boreholes in soil and solid rock have been drilled for different purposes. The lengths of these boreholes vary between a few metres to 202 m. The locations of all boreholes at drill sites DS7 and DS8 are displayed in Figure 1-2.

Results from drilling the water well HFM21 used for supply of flushing water when drilling the cored boreholes at drill site DS7 and another flushing water well at DS8 (HFM22), as well as one monitoring well in hard rock, HFM20, have been reported separately /2/. Results from geological mapping of borehole KFM07A (so called Boremap mapping) are treated in /3/. The overcoring rock stress measurements in borehole KFM07B will be presented in /4/ and the corresponding measurements in KFM07C in /5/, whereas the Boremap mapping of KFM07B and KFM07C is presented in /6/ respectively /7/.

Original data from the reported activity are stored in the primary database Sicada, where they are traceable by the Activity Plan numbers (AP PF 400-05-003 and AP PF 400-05-123). Only data in SKB's databases are accepted for further interpretation and modelling. The data presented in this report are regarded as copies of the original data. Data in the databases may be revised, if needed. Such revisions will not necessarily result in a revision of the P-report, although the normal procedure is that major data revisions entail a revision of the P-report. Minor revisions are normally presented as supplements, available at www.skb.se.

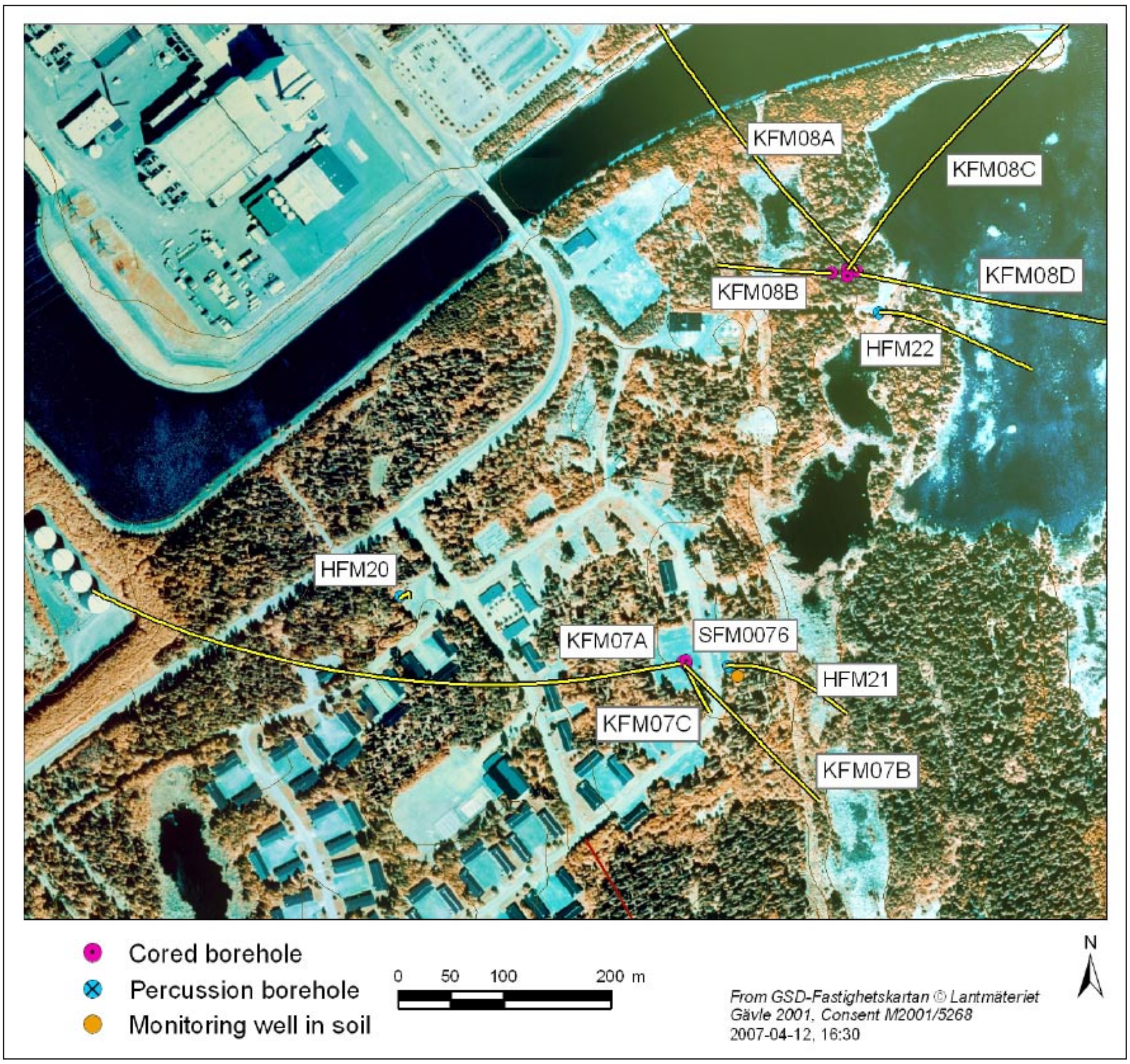


Figure 1-2. *Borehole locations at drill sites DS7 and DS8. Besides the core drilled boreholes KFM07A, KFM07B and KFM07C, the drill site incorporates a flushing water well, HFM21, and one monitoring well in the unconsolidated overburden SFM0076. A monitoring well in hard rock(HFM20) is situated about 300 m north-west of drill site DS7. The projection of inclined boreholes on the horizontal plane at the ground surface (top of casing) is shown in the figure.*

2 Objective and scope

The main objectives of drilling boreholes KFM07B and KFM07C at the site investigation were the following:

- To (by drilling of KFM07B) compensate for the missing drill core in borehole section 0–100 m in KFM07A. The rock samples collected during drilling are used for a lithological, structural and rock mechanical characterization as well as determination of the transport properties of the bedrock from the rock surface to the full drilling depth.
- To improve the poor hydraulic characterization (due to rock instabilities) performed in KFM07A of the shallow part of the bedrock (0–100 m).
- To enable rock stress measurements to repository depth. In these particular boreholes, overcoring rock stress measurements were performed during drilling and later, after completion of drilling, a stress measurement campaign by hydraulic fracturing (HF) and hydraulic testing of pre-existing fractures (HTPF) was carried out.
- To render geophysical borehole investigations possible, e.g. TV-logging, borehole radar logging and conventional geophysical logging as an aid for the geological/rock mechanical characterization.
- To allow hydraulic borehole tests (single hole tests as well as interference tests, in some cases performed as tracer tests) for characterization of the hydrogeological conditions of the bedrock.
- To enable long-term hydrogeological and hydrogeochemical monitoring at different levels of the bedrock.

Furthermore, a number of hydraulic tests and water samplings are normally performed during the drilling process, whereby a specifically designed test system, a so called wireline probe, is utilized.

3 Equipment

A Diamec 284 with HQ and a B20 with AC Corac N3/50 NT core drilling system from Atlas Copco JKS Boyles, see Figure 3-1 and Figure 3-2, were engaged for the drilling of KFM07B, whereas KFM07C was drilled with a percussion drill rig of Nemek 710 DTH type and the same B20 with AC Corac N3/50 NT core drilling system as mentioned. A short presentation of the drilling equipments is provided below.

3.1 Drilling equipment

3.1.1 Drilling equipment on KFM07B

The drilling process was first operated by a Diamec 284 machine which is supplied with an electrically-driven hydraulic system. A photo of the Diamec-system is displayed in Figure 3-1. After setting the inner support casing, a change to a B20 machine (Figure 3-2) was made. The drilling capacity of a B20 for NT (69.9 mm) holes is maximum about 1,500 metres. The drill pipes and core barrel used (Corac N3/50 NT) is a variety of the Corac N wireline system developed to fit SKB's need for "triple tube wireline" with a dimension larger than 50 mm. Technical specifications of the drilling machines with fittings are given in Table 3-1.

Core drilling with a wireline system entails recovery of the core barrel via the drill pipe string, inside which it is hoisted up with the wireline winch. During drilling of borehole KFM07B, a 3 m triple tube core barrel was used. The nominal core diameter for the Ø 75.7 mm part of the borehole is 50.2 mm. Minor deviations from this diameter may however occur.

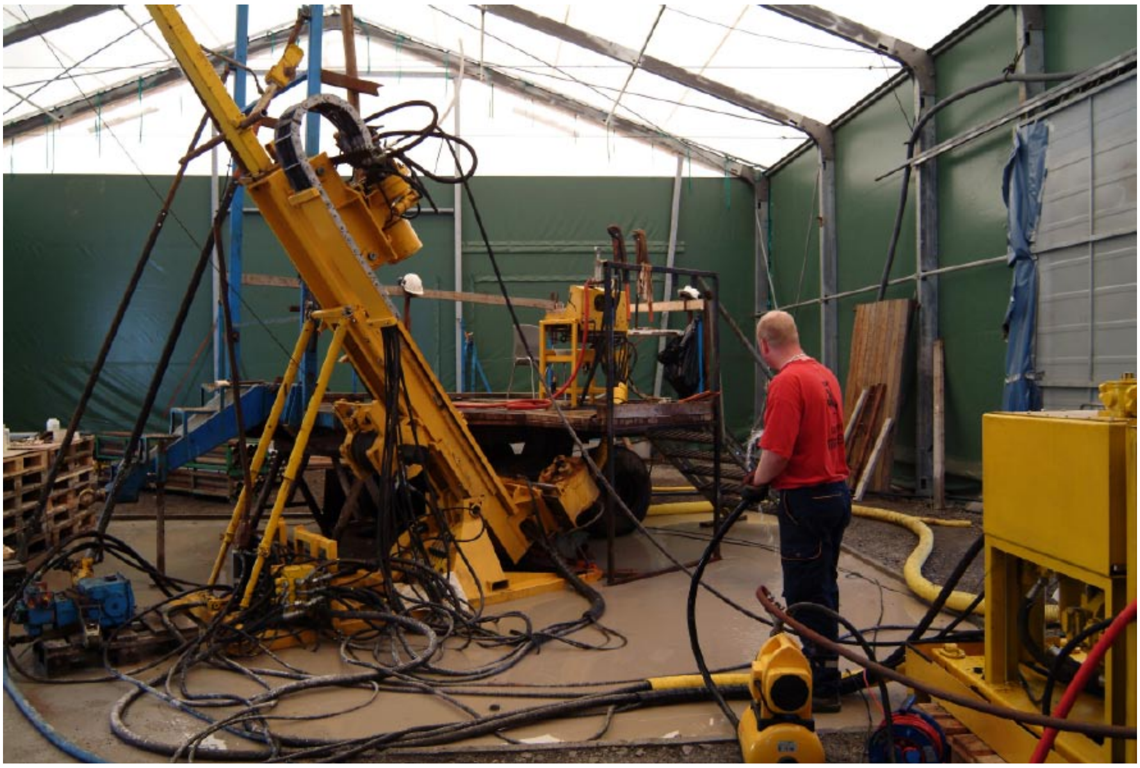


Figure 3-1. *The Diamec 284 core drilling machine in operation on borehole KFM07B.*

Figure 3-2. *The B20 core drilling machine in operation on borehole KFM07B.*

Table 3-1. Technical specifications of the drilling machines with appurtenances.

Unit	Manufacturer/type	Specifications
Nemec 710	Nemek AB	
DTH drill hammer	Secoroc 5"	10 metric ton retrac force feed system
Pipe string	Driconeq 76 mm	
Compressor	Atlas Copco XRVS 455 Md	Max pressure: 27 bars
Diamec 284	Atlas Copco	Capacity for HQ rods maximum approx. 600 m
Flush water pump	Trido 140 H	Max flow rate: 140 L/min Max pressure: 70 bars
B20	Atlas Copco JKS Boyles	Capacity for NT rods maximum approx. 1,500 m
Flush water pump	Trido 140 H	Max flow rate: 140 L/min Max pressure: 70 bars
Submersible pump	Grundfos SQ	Max flow rate: 200 L/min

3.1.2 Drilling equipment on KFM07C

The drilling process was first operated by a percussion drilling machine of Nemek 710 DTH type and continued with a B20 with AC Corac N3/50 NT core drilling system from Atlas Copco JKS Boyles (Figure 3-2). Technical specifications of the drilling machines with fittings are given in Table 3-1.

3.1.3 Rock stress measurement device

A three-dimensional *Borre* probe (Figures 3-3, 3-4 and 3-5) equipment was used for the rock stress measurements in KFM07B and KFM07C.

Figure 3-3. *Example of an overcored rock sample and the Borre probe from KFM07B.*

Figure 3-4. *A set of strain ganges to be mounted on the Borre probe used for rock stress measurements.*

Figure 3-5. *Data from the logger unit, part of the Borre probe system, are transferred to the portable computer.*

3.1.4 Flushing/return water system – function and equipment

Core drilling involves pumping of flushing water down the drill string, through the drill bit and out into the borehole in order 1) to conduct frictional heat away from the drill bit, and 2) to enhance the recovery of drill cuttings to the ground surface. The cuttings, suspended in the flushing water (in general mixed with groundwater), are forced from the borehole bottom to the ground surface via the gap between the borehole wall and the drill pipes. A schematic illustration of the flushing/return water system when drilling KFM07B and KFM07C at DS7 is shown in Figure 3-6. Below, the following equipment systems and their functions are briefly described:

- equipment for preparing the flushing water,
- equipment for storage and discharge of return water.

Preparing the flushing water

The water well used for the supply of flushing water for core drilling of KFM07B and KFM07C was a percussion drilled well in hard rock, HFM21 (see Figure 1-2), situated approximately 25 m from the two core boreholes to be drilled.

Even though the boreholes were not prioritized for chemical sampling the flushing water was still prepared in several steps before use, in accordance with SKB MD 620.003 (Method description for core drilling):

1) Incoming water from the water well was pumped into the flush water tank (see Figure 3-6).
2) Nitrogen was bubbled through the water in the tank in order to expel oxygen which might be dissolved in the water (see Figure 3-6). Expelled oxygen was discharged through a pressure reducing valve. Oxygen must be avoided in the flushing water because it is a critical parameter in the programme for hydrogeochemical characterization of the groundwater. The water was then kept continuously under a positive nitrogen pressure (about 1 bar) until pumped down into the borehole.
3) After leaving the water tank, the flushing water was exposed to UV-radiation (inside the measurement station) before entering the tracer doser equipment, illustrated in Figure 3-6. The microbe content in the water was thereby radically reduced.
4) An organic tracer dye, Uranine, was added by the tracer doser at a concentration of 0.2 mg/L, before the water was pumped into the borehole, see Figure 3-6. Labelling the flushing water with the tracer aims at enabling detection of the flushing water content in groundwater samples collected in the borehole during or after drilling.

Measurement of flushing water parameters

The total quantity of water supplied to the borehole was acquired by counting the number of filled water tanks used, multiplied by the tank volume.

Storage and discharge of return water

The return water was discharged from the borehole from the discharge head, via an expansion vessel and a flow meter to three containers, in which the drill cuttings separated out in the sedimentation container, see Figure 3-6. Since the return water had an increased salt content, it could not, for environmental reasons, be discharged into any fresh water recipient, but had to be pumped from the container via a 1 km long pipe string to the Baltic Sea. Intermittently, the return water was, after separation of drill cuttings, stored in an elastic return water tank with an expansive capacity of up to 40 m^3.

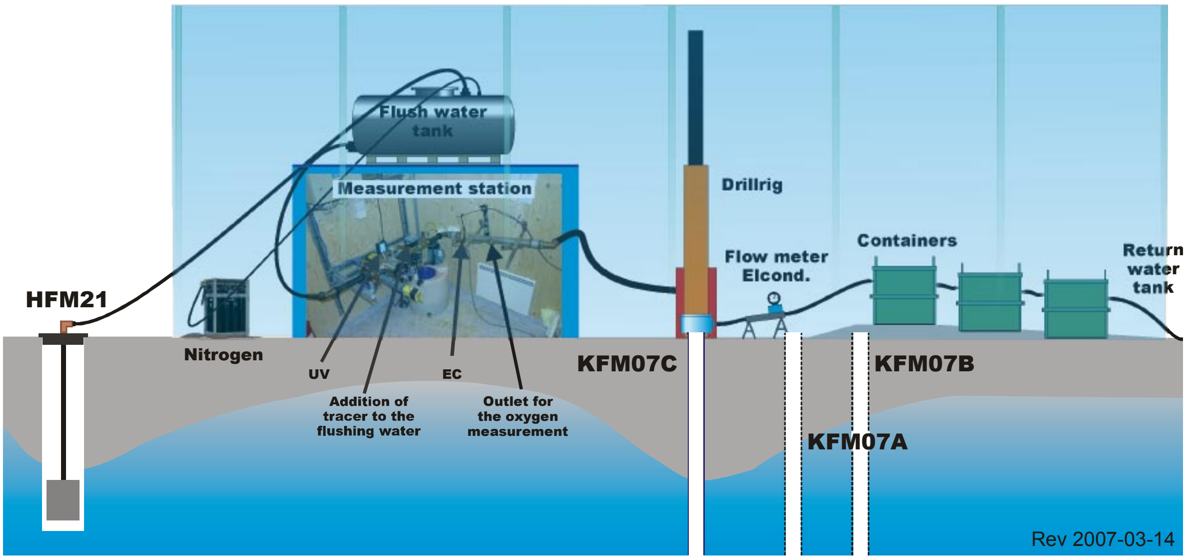


Figure 3-6. *Schematic illustration of the flushing/return water system when drilling KFM07B and KFM07C at DS7. For measurements of the accumulated return water volume, a mechanical water gauge was used.*

3.1.5 Groove milling equipment

After completion of drilling, boreholes KFM07B and KFM07C have been used and will further be used for a variety of borehole measurements, employing many types of borehole instruments with different stretching characteristics (pipe strings, wires, cables etc). In order to provide a system for length calibration in the boreholes, reference grooves have been milled into the borehole wall with a specially designed tool at regular levels. This was carried out after drilling, but with use of the drilling machine and drill pipe string.

At each level where milling was performed, two 20 mm wide grooves were milled with a distance of 10 cm between them, see Figure 3-7. After milling, the reference grooves were detected with the SKB level indicator (a calliper). A BIPS-survey provided the final confirmation that the grooves exist.

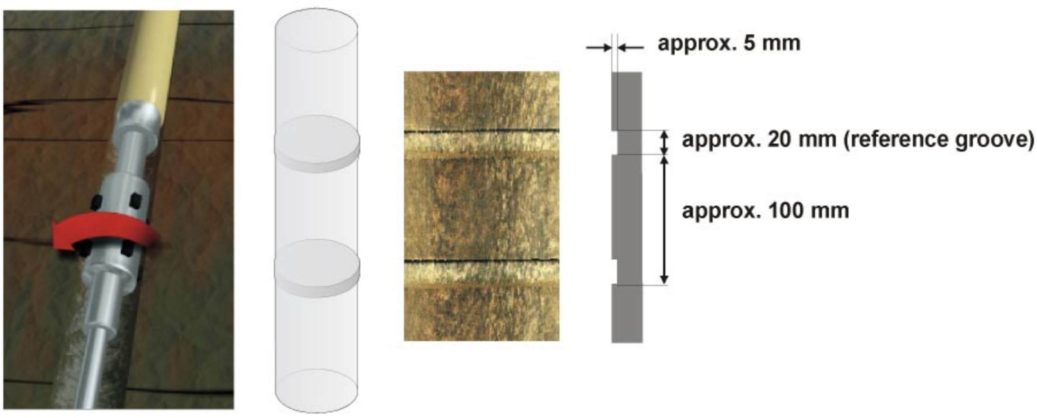


Figure 3-7. *Layout and design of reference grooves.*

3.1.6 Equipment for deviation measurements

After completion of drilling, a deviation measurement was carried out with a Reflex MAXIBOR™-system, which is an optical, i.e. non-magnetic measurement system. Azimuth and dip are measured at every third metre. The collaring point coordinates and the measured values are used for calculating the coordinates of the position of the borehole at every measurement point.

Also another method, based on magnetic-accelerometer technique, was applied for deviation measurements in order to check the validity of the MAXIBOR™-measurements. The surveying instrument used was the FLEXIT Smart Tool System.

At the time of drilling KFM07B and KFM07C, the MAXIBOR™-method was assessed as the most reliable of different deviation methods tested by SKB, and MAXIBOR-data stored in the database Sicada were normally assigned as the only deviation data set permitted to be used (so called "in use displayed data") even if another or several deviation methods had been applied in a borehole as well. However, in connection with a major quality revision regarding orientation of all identified geological objects (fractures, fracture zones rock contacts etc) conducted by SKB during late autumn 2006 to winter/early spring 2007, a reassessment of the reliability of deviation measurement methods was made, whereby the FLEXIT-method was judged as providing the most reliable results. Therefore a revision was made also for boreholes KFM07B and KFM07C, and to-day FLEXIT-data provide the in use displayed deviation data set. However, results from all available deviation measurements for boreholes KFM07B and KFM07C, FLEXIT- as well as MAXIBOR-data, have been used for estimation of the uncertainty of deviation data.

Results from the deviation measurements stored in Sicada are presented in Sections 5.5.3 and 5.10.4.

3.1.7 Equipment for hydraulic tests, absolute pressure measurements and water sampling during drilling

In SKB MD 620.003 it is stated that hydraulic tests, absolute pressure measurements and water sampling should be performed at certain intervals using a down-hole tool specially designed for the Corac system. The tool, which is denominated "the wireline probe" or "WL-probe", is described in SKB MD 321.002, see Table 1-1.

3.1.8 Equipment for borehole stabilization

A new technique for stabilization of borehole walls, designated the PLEX-technique, has just recently been developed and tested by SKB, see Figure 3-8. The PLEX-system can be applied for mechanical stabilization of unstable parts of the borehole wall after part of or the entire borehole has been drilled. The system components, comprising a reamer, a packer with a steel plate (perforated or non-perforated) and a top valve, are assembled on top of each other in one single unit. The tool is designed for the N-dimension. By using the same pilot drill bit and ring gauge as used for drilling the borehole in question, the tool is well adjusted to the true borehole diameter. Only one rod trip is required for reaming, expanding the steel tube and verifying the inner diameter of the borehole. Using a perforated or non-perforated steel plate is optional. A perforated plate is applied if hydraulic characterization of the unstable section remains to be done.

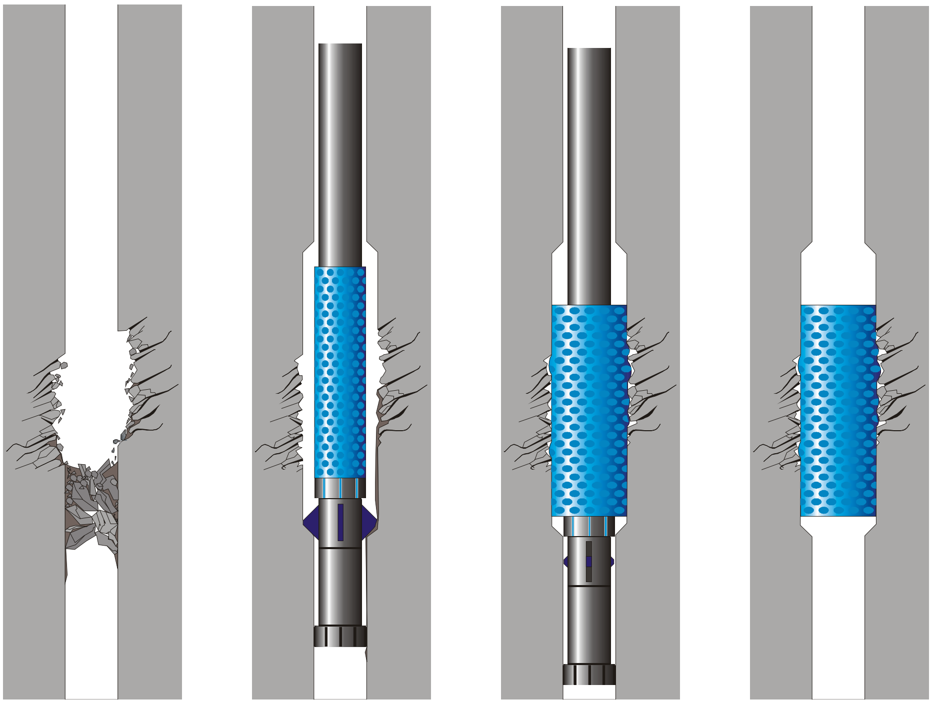


Figure 3-8. *Schematic figure illustrating the sequence of measures when stabilizing a fractured and unstable section in a core drilled borehole of N-dimension with a perforated steel plate by applying the PLEX-system. The tool is descended, the 198 cm long unstable section is reamed, the packer is inflated as to expand the steel plate against the reamed part of the borehole wall, the packer is deflated and the tool is retrieved. As the steel tube is perforated, the stabilization does not prevent hydraulic testing of the stabilized section.*

4 Execution

4.1 General

The activity of drilling KFM07B and performance of contemporaneous overcoring rock stress measurements was conducted in compliance with Activity Plan AP PF 400-05-003, whereas the corresponding activity in KFM07C was carried out according to Activity Plan AP PF 400-05-123, both referring to SKB MD 620.003 (method description for core drilling), see Table 1-1. The drilling operations included the following parts:

- preparations,
- mobilisation, including lining up the machine and measuring the position,
- drilling, measurements, over-coring and sampling during drilling,
- finishing off work,
- data handling.

The items are presented more in detail in Sections 4.2–4.7.

4.2 Preparations

The preparations included the Contractor's service and function control of his equipment. The machinery was supplied with fuel, oil and grease entirely of the types stated in SKB MD 600.006 (SKB method instruction). Finally, the equipment was cleaned in accordance with SKB MD 600.004 (SKB method instruction).

4.3 Drilling KFM07B

4.3.1 Mobilization

Mobilization onto and at the site included preparation of the drill site, transport of drilling equipment, flushing water equipment, sampling boxes for drill cores, as well as hand tools etc. Furthermore, the mobilization consisted of cleaning of all in-the-hole equipment at level one in accordance with SKB MD 600.004, lining up the machine and final function control of all equipment.

4.3.2 Drilling of section 0–65.69 m

Drilling started with the Diamec 284 machine with HQ (96 mm) down to 6.89 m followed by reaming with B116 mm to 5.18 m and cement grouting. The soil depth was 2.89 m. Drilling continued with HQ 96 to 65.69 m and installation of an inner support casing to 65.29 m with OD/ID 90/77 mm, which was cement grouted.

4.3.3 Drilling, measurements and sampling during drilling of section 65.69–298.93 m

By core drilling of borehole KFM07B, two borehole dimensions were applied. Below section 3.73–65.69 m, which was drilled with Ø 96 mm with the Diamec machine, the main part of the borehole, section 65.69–298.93 m, was drilled with the B20 machine with a diameter of 75.8 mm.

Core drilling at the SKB site investigation is associated with a programme for sampling, measurements and other activities during and immediately after drilling, cf. SKB MD 620.003. However, for different reasons, during drilling of KFM07B some deviations from this programme could not be avoided. The major discrepancy compared to SKB MD 620.003 was the overcoring rock stress measurements during drilling. In order to elucidate the nonconformities, the programme according to the method description is presented in Section 4.7, Table 4-1, together with the actual performance when drilling KFM07B.

Results from the measurements and registrations during core drilling are presented in Chapter 5.

4.3.4 Guided drilling

Guided drilling was made in the following sections 166.82–171.07 m, 174.21–176.59 m, 179.63–182.60 m, 188.31–190.65 m, 190.65–195.94 m, and 205.71–208.62 m in order to restore the borehole orientation to the starting values.

4.4 Drilling KFM07C

4.4.1 Mobilization

Mobilization onto and at the site included preparation of the drill site, transport of drilling equipment, flushing water equipment, sampling boxes for drill cores, as well as hand tools etc. Furthermore, the mobilization consisted of cleaning of all in-the-hole equipment at level one in accordance with SKB MD 600.004, lining up the machine and final function control of all equipment.

4.4.2 Percussion drilling of section 0–85.15 m

Drilling started with the Nemek machine with NO-X 281 down to 6.23 m followed by drilling to 85.15 m with the diameter 157.4 mm, reaming to 85.10 m with diameter 243.3 mm and cement grouting. The soil depth was approximately 3.55 m.

4.4.3 Core drilling, measurements and sampling during drilling of section 85.15–500.34 m

By core drilling of borehole KFM07C, two borehole dimensions were applied. Section 85.15–86.75 m was drilled with 75.8 mm, where after the section to 88.55 m was reamed to 86 mm. Drilling continued with 75.8 mm but an unstable and highly permeable section at c. 93 m made it difficult to proceed the rock stress measurements and drilling was interrupted at 152.47 m. Instead the borehole section from 86.75 m to 98.42 m was reamed to 86 mm and a temporary casing shield off the zone while drilling with 75.8 mm to 500.34 m was performed.

The B20 machine was employed for the core drilling operations.

Regarding the programme for sampling, measurements and other activities during and immediately after core drilling, like when drilling of KFM07B some deviations from this programme were made, and the major discrepancy compared to SKB MD 620.003 was also in this case due to the overcoring rock stress measurements during drilling. The programme according to the method description is presented in Section 4.7, Table 4-1, together with the actual performance when drilling KFM07C.

Results from the measurements and registrations during core drilling are presented in Chapter 5.

4.5 Finishing off work in KFM07B and KFM07C

The concluding work included the following items:

1) The boreholes were flushed for about 10 hours in order to clean them from drilling debris adhered to the borehole walls, settled at the bottom of the hole or suspended in the water.
2) The drill string was pulled.
3) The borehole was secured with a lockable stainless steel flange.
4) The core drilling equipment was removed, the site cleaned and a joint inspection made by SKB and the Contractor.

4.6 Data handling/post processing for KFM07B and KFM07C

Minutes for several items with the following headlines: Activities, Cleaning of the equipment, Drilling, Borehole, Core drilling penetration rate, Deliverance of field material and Discrepancy report were filled in by the field crew, and collected by the Activity Leader, who made a control of the information and had it stored in the SKB database Sicada where they are traceable by the activity plan number.

4.7 Nonconformities

Nitrogen air flushing was performed in order to improve cleaning of the borehole from drilling debris.

The core drilling operation resulted in a number of nonconformities with the Method Description. These are presented in Table 4-1 below.

Table 4-1. Programme for sampling, measurements, registrations and other activities during and immediately after core drilling according to SKB MD 620.003 AP PF 400-05-003 and AP PF 400-05-123, and the actual performance during drilling of boreholes KFM07B and KFM07C.

Activity	Performance and frequency according to SKB MD 620.004 and, for the last item, AP PF 400-05-003 and AP PF 400-05-123	Performance and frequency during drilling of KFM07B	Performance and frequency during drilling of KFM07C
Registration of drilling- and flushing water parameters.	Registration during the entire drilling.	According to programme. 0–65.69 m was drilled without registration.	According to programme.
Core sampling.	Continuous sampling of the entire drilled section.	According to programme.	According to programme.
Deviation measurements.	Normally performed every 100 m and after completion of drilling.	One MAXIBOR-measurement after completion of drilling and four measurements with FLEXIT at different length of the borehole.	One MAXIBOR-measurement after completion of drilling and one measurement with FLEXIT.
Hydraulic tests.	Normally performed every 100 m, and also when penetrating larger conductive fractures/zones. The tightness of the drill pipe string should be controlled before each test.	No measurements performed.	No measurements performed.
Water sampling.	Normally performed every 100 m, and also when penetrating larger conductive fractures/zones. The tightness of the drill pipe string should be controlled before each test.	No measurements performed.	No measurements performed.
Absolute pressure measurements.	Normally during natural pauses in drilling.	No measurements performed.	No measurements performed.
Groove milling in the borehole wall, normally at each 50 m.	Normally performed after completion of drilling.	Four grooves performed.	Seven grooves performed.
Over-coring rock stress measurements.	Measurements at 5-6 different levels.	Performed at 75 m, 150 m and 220 m.	Performed at 90 m, 160 m, 195 m, 250 m, 320 m and 420 m.

5 Results

All data were stored in the Sicada database. Results from borehole KFM07B are presented in Section 5.1 and from borehole KFM07C in Section 5.2. An overview of the drilling progress of borehole KFM07B is given in Section 5.1, whereas geometrical data and technical design are presented in Section 5.2.

5.1 KFM07B

An overview of the drilling progress of borehole KFM07B is given in Section 5.1.1, whereas geometrical data and technical design are presented in Section 5.1.2.

Results from drilling and measurements during drilling are accounted for in:

- Section 5.1.3 (drilling 0–65.69 m).
- Section 5.1.4 (drilling 65.69–298.93 m).
- Section 5.1.5 (measurements while drilling).

Well Cad-presentations of borehole KFM07B are shown in:

- Appendix A.

The Well Cad plots are composite diagrams presenting the most important technical and geoscientific results from drilling and investigations made during and immediately after drilling.

5.1.1 Drilling progress

Drilling of borehole KFM07B was carried out during a period of slightly more than 4 1/2 months including summer holidays, see Figure 5-1. The prolonged drilling period was mainly due to the much time consuming overcoring rock stress measurements, but partly also to the drilling performance with only one shift/day.

5.1.2 Geometrical and technical design KFM07B

Administrative, geometric and technical data for the core drilled borehole KFM07B are presented in Table 5-1. The technical design of the borehole is illustrated in Figure 5-2.

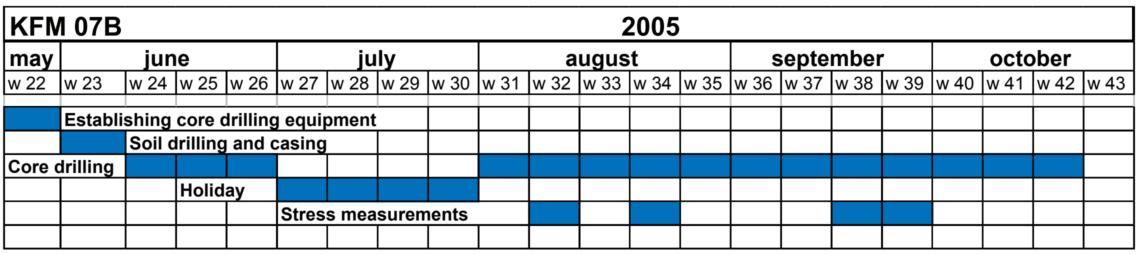


Figure 5-1. Overview of the drilling performance of borehole KFM07B.

Table 5-1. Administrative, geometric and technical data for borehole KFM07B.

Parameter	
Borehole name	KFM07B
Location	Forsmark, Östhammar municipality, Sweden
Drilling start date	May 30, 2005
Completion date	October 18, 2005
Drilling period	2005-05-30 to 2005-06-20 (0–65.69 m)
	2005-08-07 to 2005-10-18 (65.69–298.93 m)
Contractor core drilling	Drillcon Core AB
Core drill rig	Atlas Copco Craelius B20
Position KFM07B at top of casing (RT90 2.5 gon V 0:–15/RHB 70)	N 6700123.62 E 1631036.83 Z 3.36 (m. a. s. l.) Azimuth (0–360°): 134.35° Dip (0–90°): –53.71
Position KFM07B at bottom of hole (RT90 2.5 gon V 0:–15/RHB 70)	N 6699992.78 E 1631164.75 Z –232.98 (m. a. s. l.) Azimuth (0–360°): 135.21° Dip (0–90°): –51.65°
Borehole length	298.93 m
Borehole diameter and length	From 0 m to 5.18 m: 116 mm From 5.18 m to 65.69 m: 96 mm From 65.69 m to 298.93 m: 75.8 mm
Casing diameter and length	$Ø_o/Ø_i$ = 90 mm/78 mm to 65.29 m
Drill core dimension	3.73–65.69 m/Ø 63.3 mm 65.69–298.93 m/Ø 50.5 mm
Core interval	3.73–298.93 m

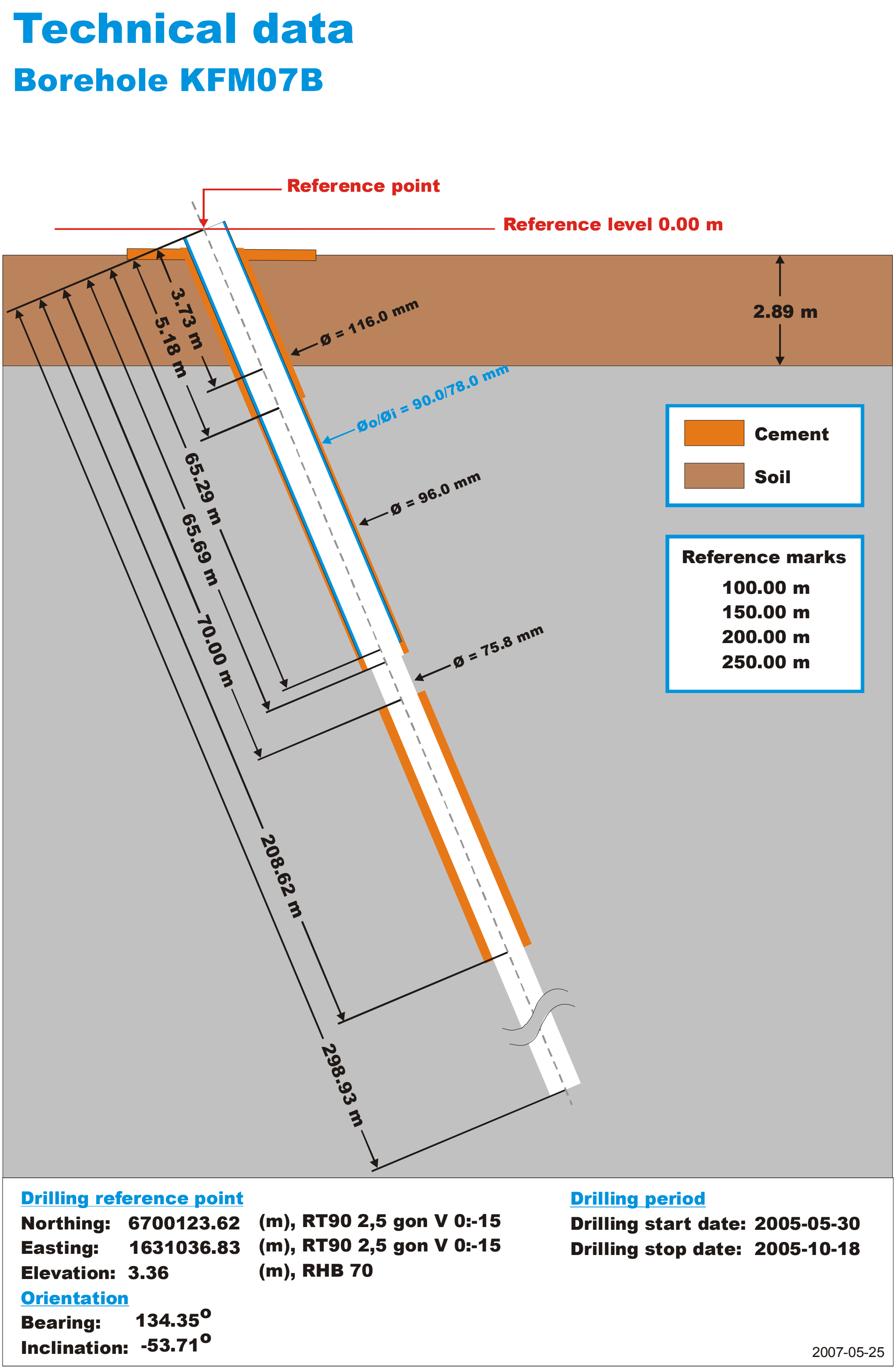


Figure 5-2. Technical data of borehole KFM07B.

5.1.3 Drilling section 0–65.69 m in KFM07B

The experience from previous rock stress measurements with the overcoring technique in borehole KFM01B indicates that the magnitude of the rock stress field at Forsmark, at least at greater depths, is close to the limit where the used measuring technique works satisfactory. At high stress levels, especially when high deviatoric stresses prevail, there is an increased risk of microfracturing in the hollow drill core in which the stress measurements are performed, and in the worst case, core discing occurs, i.e. the drill core is split up into thin discs. When planning continued stress measurements in the Forsmark granite, great consideration was taken to optimize the conditions for fulfilling an overcoring measurement programme. To minimize the risk of microfracturing/core discing in KFM07B, the borehole was inclined in order to as close as possible follow strike and dip of the major principal stress, which at Forsmark is near horizontal. However, this strategy was not optimal, because major problems described below to clean the flat borehole from drilling debris appeared.

Drilling of the section 0–65.69 m was progressing between May 30th to June 20th, 2005 (Figures 5-1 and 5-3). As mentioned in Section 4.3.2, the upper part down to 65.29 m of the borehole is supplied with a 90/78 mm steel casing. In Section 4.3.3 a description of the core drilling from 3.73 to 65.69 m with a borehole diameter of 96 mm was given. Section 0–65.69 m was also cement grouted.

5.1.4 Drilling section 65.69–298.93 m in KFM07B

The core drilling progress during the period from August 7th, 2005 to October 18th, 2005 is presented in Figure 5-3. This borehole was designed for rock stress measurements with the overcoring technique. The measurement technique for performance of overcoring measurements is to glue a suite (so called rosette) of strain gauges onto the wall of the short narrow pilot borehole, which is drilled at the bottom of the cored borehole at each measurement level. In order to obtain optimal gluing, it is necessary that the borehole wall is absolutely clean, i.e.

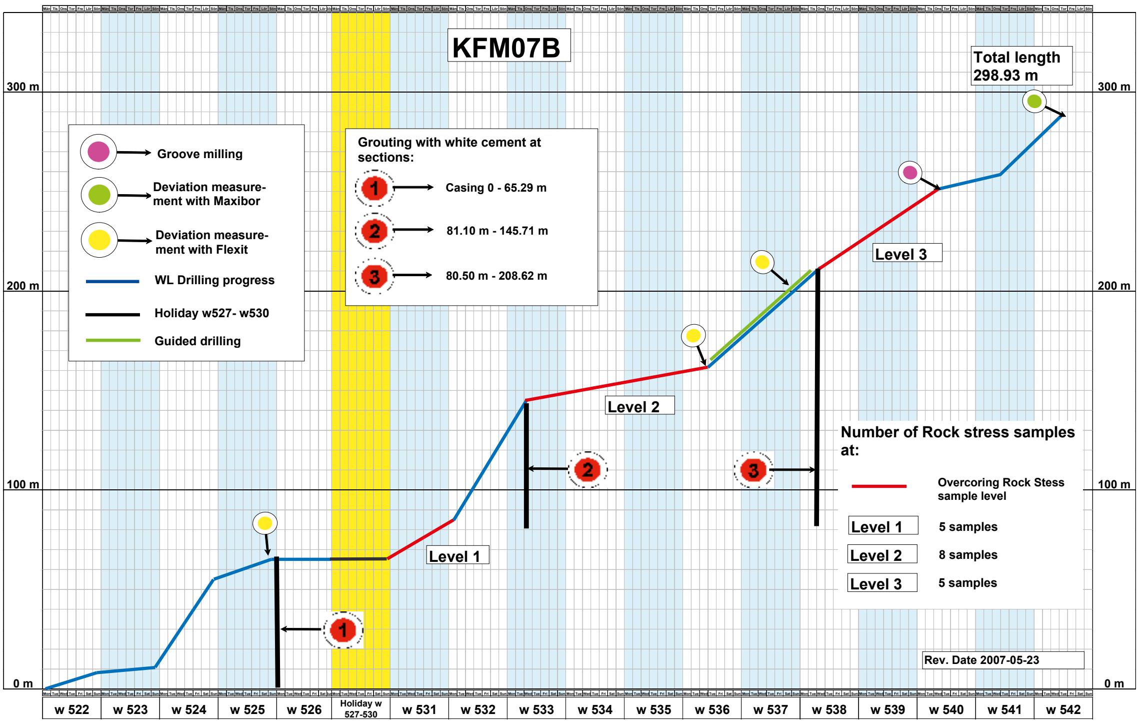


Figure 5-3. Core drilling progress KFM07B (length versus calendar time).The diagram is also illustrating the logistics for cement grouting, rock stress measurements with selected overcoring levels, guided drilling, groove milling and deviation measurements.

that all drilling debris and other particles have been removed, which is normally achieved by the high pressure flushing water. Therefore it is essential that the borehole above the measurement levels do not penetrate too many conductive fractures, because much of the flushing water will then be injected into these fractures, thereby reducing the available amount of flushing water for cleaning the borehole wall at depth, where the rock stress measurement cell is to be installed. Furthermore, by discharge of flushing water from the borehole into conductive fractures, also drilling debris may be injected. When the drill string is pulled in the borehole, thereby creating a pressure gradient into the borehole, drill cuttings may again be withdrawn from the fractures and gradually settle at the borehole bottom or adhere to the borehole wall (especially at the lower wall).

The previous drilling of KFM07A demonstrated the existence of a near horizontal fractured zone at c. 50 m vertical depth at DS7, which was expected to appear also in KFM07B. Therefore, the upper section between 0–65.29 m was drilled with HQ (Ø 96 mm), supplied with a casing and cement grouted. The water inflow thereby decreased to a minimum.

The rock stress measurements at level 1 (see Figure 5-3) started just below the casing, but further down, in a fractured section around c. 91 m, some broken pilot cores were retrieved, indicating a fractured and water yielding section, unsuitable for overcoring measurements. Therefore the borehole was deepened, and the measurements resumed further down.

When the borehole had passed through the permeable zone at 91 m, flushing water with drilling debris was pressed into it, again entailing the cleaning problems described above. A decision was therefore made to grout part of the borehole. This grouting comprised injection with 2,175 kg white cement and was performed from 81.80 m to the bottom of the borehole at 145.71 m.

Rock stress measurement were taken up again at level 2 (see Figure 5-3), however with increasing difficulties of cleaning the pilot hole, in spite of the grouting performed. Possibly, the earlier grouted fractures in the upper part of the borehole had partly re-opened, and thereby water and drill cuttings could return back into the borehole. Furthermore, deviation measurements indicated a successively decreased inclination, i.e. increased flatness of the borehole, which also could contribute to the insufficient cleaning effect. It was therefore decided to perform guided drilling until the inclination had been corrected to the initial value, and to perform a new grouting. Guided drilling is described below in this section. The second grouting with approximately 750 kg white cement was carried out in section 80.50–208.62 m.

In spite of all efforts that were made, the achievement to obtain acceptable stress measurements with the overcoring technique at level 3 (see Figure 5-3) failed, and therefore the borehole was ended at 298.93 m. A conclusion that may be drawn is that inclined, conventional boreholes are not optimal for conducting rock stress measurements with overcoring technique due to the reasons described above. The situation may however be different when drilling underground boreholes where an excess groundwater pressure is directed from the formation towards the borehole, which hence will be continuously flushed by the groundwater flowing through the borehole.

Core sampling KFM07B

A preliminary on-site core logging was performed continuously.

Guided drilling KFM07B

Deviation measurements performed during the drilling/rock stress measurement campaign in KFM07B indicated a tendency of the borehole to deviate upwards, i.e. the inclination decreased successively. Because of the above described cleaning problems partly caused by the flatness of the borehole, it was regarded as essential to correct the inclination. Also the borehole azimuth showed some deviation to the right, away from the strike of the major principal stress. Therefore guided drilling was applied in section 166–208 m in order to steer the borehole as close as possible back to the initial starting values.

Usually, inclined boreholes drilled in the Forsmark granite, deviate upwards and to the right versus depth. Borehole KFM07B was directed 134.35º from north and inclined –53.71º, see Table 5-1 and Figure 5-2. At 165 m drilling length, the inclination had decreased to –52.00º and the bearing increased to136.09º, and it was obvious that the borehole should continue going upwards. Guided drilling was therefore performed, focusing more on correcting the borehole inclination than of on the bearing, in sections 166.82–171.07 m, 174.21–176.59 m, 179.63–182.60 m, 188.31–190.65 m, 190.65–195.94 m, and 205.71–208.62 m. After these six guided drilling sections had been completed, the bearing value was back close to the original orientation, see Table 5-2, whereas the inclination had increased a bit beyond the original value, making the borehole a little steeper than before. Although this was the first time guided drilling was tested in Forsmark, the used technique worked satisfactory.

Rock stress measurement KFM07B

During the period August 1st, 2005 to October 6th, 2005, overcoring stress measurements were conducted in the inclined borehole KFM07B with the three-dimensional *Borre* probe. Measurements were attempted at three levels (67.71–72.98 m, 157.37–160.48 m and 208.62–251.73 m) in the borehole. Due to the character of the stress field with high deviatory stresses, several measurement attempts failed because of microfracturing in the overcored rock samples. As described above, another major problem was connected to difficulties of cleaning the borehole efficiently, which rendered gluing of the strain gauges towards the pilot borehole wall troublesome. Due to the problems encountered, the stress measurements were interrupted halfway through the planed programme. The results of the rock stress measurements in KFM07B will be presented in /4/.

5.1.5 Measurements while drilling KFM07B

During, and immediately after drilling, a program for sampling and measurements was applied, cf. Section 4.3.3. Some of the results are displayed in the Well Cad-presentation in Appendix A (deviation measurements, penetration rate and rock type distribution), whereas other results (flow data and electrical conductivity) are only used as supporting data for on-site decisions. Below, the results of the water balance measurements, determinations of the Uranine content, groove milling and deviation measurements made after completed drilling of KFM07B are commented on.

Table 5-2. Deviation data from KFM07B. Note the small discrepancy between the start values of orientation data compared to orientation values at 210 m when the guided drilling was finished.

Length (m)	Vertical depth (m)	Inclination (degrees)	Bearing (degrees)
0	0	–53.71	134.35
165	1,330	–52.00	136.09
168	135.4	–52.22	136.22
171	137.8	–52.87	136.15
174	140.1	–52.95	136.00
177	142.5	–53.40	135.56
180	145.0	–53.45	135.38
183	147.4	–53.85	135.20
186	149.8	–53.86	135.01
189	152.2	–53.88	134.91
192	154.6	–54.09	134.99
195	157.1	–54.40	134.88
198	159.5	–54.53	134.87
201	162.0	–54.53	134.78
204	164.4	–54.51	134.75
207	166.8	–54.51	134.75
210	169.3	–54.69	134.89

Flushing water and return water flow rate – water balance in KFM07B

Figure 5-4 displays the accumulated volumes of flushing water respectively return water from the entire drilling period. From the accumulated volumes of flushing water and return water at the end of the drilling period the return water/flushing water quotient may be calculated, in this case resulting in the quotient 1.53.

Uranine content of flushing water in KFM07B

An organic tracer, Uranine, was automatically added to the flush water tank, see Section 3.1.4. During the drilling period, sampling of flushing water and analyses of the tracer content was performed systematically with a frequency of approximately one sample per 20–30 m drilling length, see Figure 5-5. The concentration of Uranine has been very stable except from 3 occasions. At these occasions there was either some problems with the automatic dose equipment or lack of Uranine in the dose tank. During those occasions there was only a small amount of water that was pumped into the borehole so the problem is of minor importance.

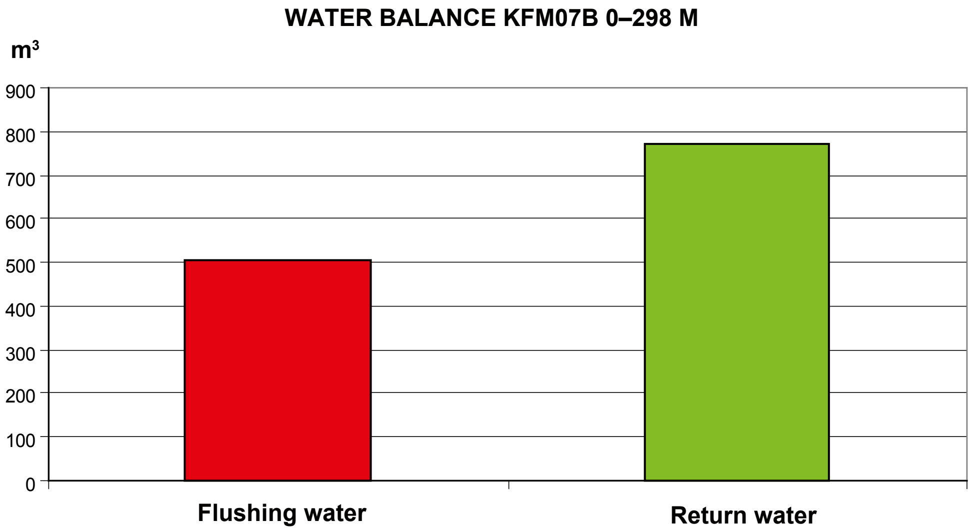


Figure 5-4. *The total volume of flushing water used during core drilling of KFM07B was 503 m³. During the same period, the total volume of return water was 770 m³. The return water/flushing water balance is then 1.53, i.e. much over 1.0 due to a successful grouting in section 80–210 m that sealed water-conductive fractures.*

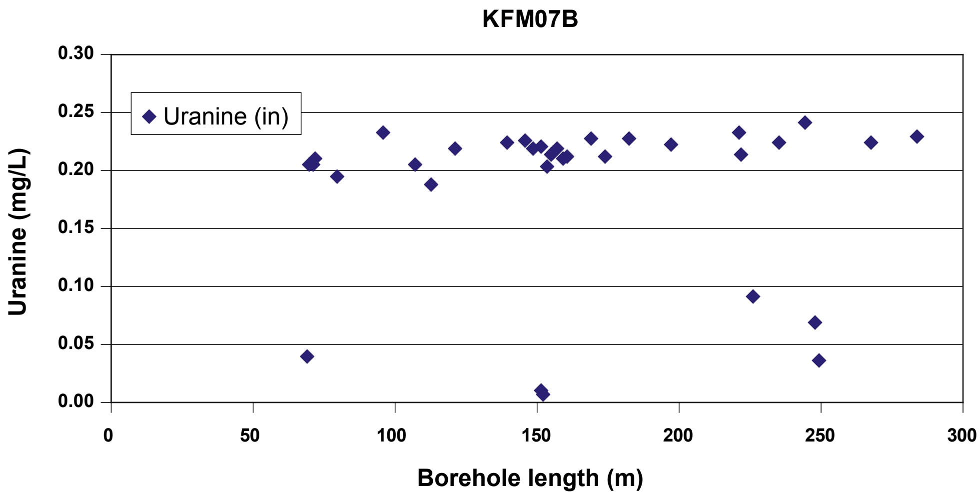


Figure 5-5. *Uranine content versus drilling length in flushing water during drilling of borehole KFM07B.*

Groove milling KFM07B

A compilation of length to the reference grooves and if they were detected is given in Table 5-3. The positions of the grooves are determined from the length of the drilling pipes used at the milling process. The length is measured from the upper part of the upper two grooves.

Deviation measurements in KFM07B

The principles of the equipment for deviation measurements were explained in Section 3.1.6. Also the changed strategy for deviation measurements during the site investigations was commented on, including the fact that the FLEXIT-method is now the principal method applied for deviation measurements, also in borehole KFM07B. When MAXIBOR™-measurements or deviation measurements with some other method have been performed as well, these are used for uncertainty determinations of the deviation measurements, if they are technically successful.

The quality control program of deviation measurements is mostly concentrated to handling of the instrument as well as to routines applied for the performance. It is not possible to execute an absolute control measurement, as no long borehole is available with access both to the borehole collar and the borehole end. The surveying instrument for the principal method applied to-day is the FLEXIT Smart Tool System. To ensure high quality measurements with the FLEXIT-tool, the disturbances of the magnetic field must be small. In Uppsala, a measuring station provides one-minute magnetic field values that are available on the Internet at www.intermagnet.org and gives sufficient information. The magnetic field variation during November 6th, 2006, is seen in Figure 5-6 and shows only minor disturbances when the FLEXIT-survey in KFM07B was performed.

Table 5-3. Reference grooves in KFM07B.

Reference groove at (m)	Detection with the SKB level indicator	Confirmed from BIPS
100	Yes	Yes
150	Yes	Yes
200	Yes	Yes
250	Yes	Yes

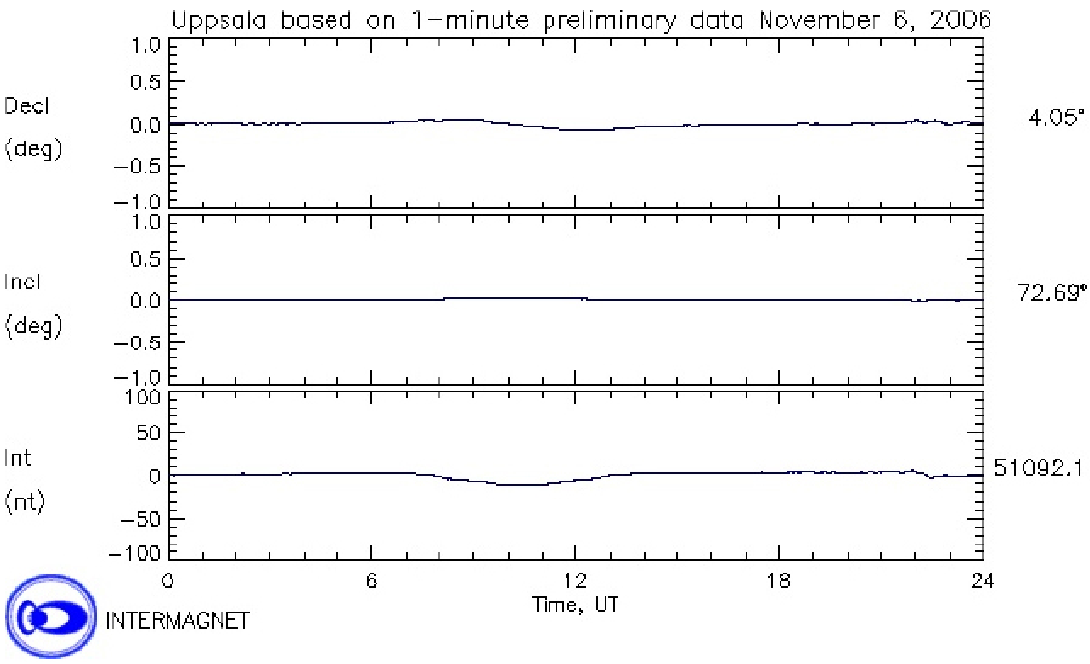


***Figure 5-6.** Magnetic field variation during the FLEXIT-survey performed on November 6th, 2006.*

The data approved in KFM07B are one complete Reflex MAXIBOR™-logging and two FLEXIT-loggings to 297 m borehole length, see Table 5-4. With the FLEXIT Smart Tool System, deviation measurements in borehole KFM07B were carried out every 3 m, both downwards and upwards. These two surveys, with activity numbers 13134861 and 13134871, provided almost repeatable results, and were therefore chosen for the construction of the deviation file to be "in use displayed" in Sicada (see explanation in Section 3.1.6). This file is designated as EG154.

The EG154-activity presented in Table 5-5 specifies the deviation measurements used in the resulting calculation. The bearing measurements start at 66 m so that the magnetometer should not be effected by the 65 m steel casing.

A subset of the resulting deviation file together with the estimated radius uncertainty is presented in Table 5-6. The radius uncertainty represents the uncertainty of the deviation measurements presented as a cone surrounding the borehole axis.

The calculated deviation (EG154-file) in borehole KFM07B shows that the borehole deviates slightly upwards but is laterally almost straight. The "absolute deviation", here defined as the shortest distance in space between any point in the borehole and the imaginary position of that point if the borehole had followed a straight line with the same inclination and bearing as of the borehole collaring, is only 5.5 m (Figure 5-7).

Table 5-4. Activity data for the three deviation measurements approved for KFM07B. The two magnetic-accelerometer measurements were used for calculation of a final borehole deviation, whereas all three measurements were used for calculation of the uncertainty.

Activity Id	Activity Type code	Activity	Start date	Idcode	Secup (m)	Seclow (m)	Flags
13092490	EG156	MAXIBOR-measurement	2005-10-19 00:00	KFM07B	0	297	
13134861	EG157	Magnetic-accelerometer measurement	2006-11-06 15:20	KFM07B	3	297	CF
13134871	EG157	Magnetic-accelerometer measurement	2006-11-06 16:45	KFM07B	3	297	CF
13140445	EG154	Borehole deviation multiple measurements	2006-12-13 11:00	KFM07B			I C

Table 5-5. Content of the EG154 file (multiple borehole deviation intervals).

Deviation Activity id	Deviation Angle type	Approved Secup (m)	Approved Seclow (m)
13134861	Bearing	66	297
13134861	Inclination	3	297
13134871	Bearing	66	297
13134871	Inclination	3	297

Table 5-6. Deviation data from KFM07B from every approx. 100 m vertical length calculated from EG154. Inclination, bearing and radius uncertainty are also included.

Borehole	Length (m)	Northing (m)	Easting (m)	Elevation (m)	Inclination (degrees)	Bearing	Inclination uncertainty	Bearing uncertainty	Radius uncertainty
KFM07B	0	6700123.622	1631036.833	3.363	–54.74	134.346	1.725	0.566	0
KFM07B	129	6700070.167	1631090.187	–101.201	–52.605	136.12	1.725	0.566	3.883
KFM07B	252	6700017.875	1631141.391	–200.033	–53.93	135.24	1.725	0.566	7.586
KFM07B	298.93	6699998.302	1631161	–237.911	–53.56	134.64	1.725	0.566	8.999

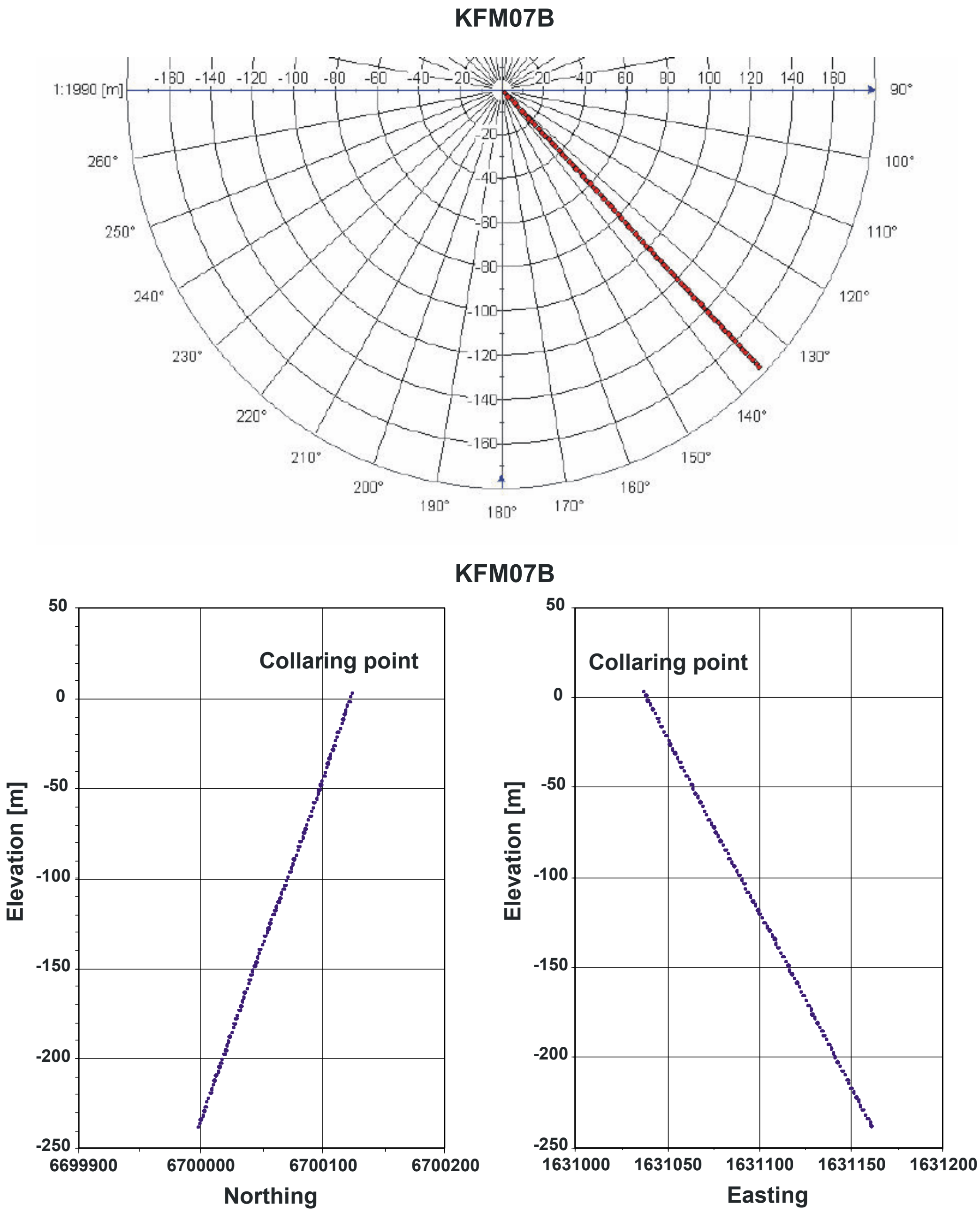


Figure 5-7. Upper figure is a horizontal projection and lower figures are two vertical projections of the measured deviation in KFM07B.

Consumables KFM07B

The special type of thread grease (silicon based) used in this particular borehole was certified according to SKB MD 600.006, Version 1.0, Instruction for the use of chemical products and material during drilling and surveys. Oil and grease consumptions are given in Table 5-7 below.

The amount and quality of grout for sealing the casing gap and tighten the borehole are reported in Table 5-8 below.

5.2 KFM07C

5.2.1 Drilling progress

In order to improve the possibility of obtaining successful overcoring rock stress measurements in borehole KFM07C, a different strategy for the borehole design compared to KFM07B was tested. KFM07C was inclined as much as about 85°, i.e. very steep, and was performed as a telescopic borehole, which enables permanent pumping and retrieval of drill cuttings during drilling.

Borehole KFM07C was drilled during a period of slightly more than four months including summer holidays, see Figure 5-8. The prolonged drilling period was mainly due to the much time consuming overcoring rock stress measurements, but partly also to the drilling performance with only one shift/day. The four weeks long annual summer holiday was also just before the end of the measuring period.

Table 5-7. Grease, oil and diesel consumption during drilling of KFM07B.

Borehole ID	**Thread grease** Üni Silikon L50/2	**Grease for the drilling machine** Castrol AB	**Engine oil Castrol** Tection 15W-40	**Hydraulic oil** Premium ECO HT-E 46	**Diesel engines** OKQ8 Diesel miljöklass 1
KFM07B	4 kg	0.8 kg	20 L	20 L	10,385 L

Table 5-8. Cement consumption KFM07B.

Borehole ID	Grouting length (m)	Cement volume (Aalborg Portland Cement/microsilica)	Grouting method	Remarks (Final pressure)	Date
KFM07B	0.00–65.69	450 kg/198 L	Packer	8 bars	2005-06-22
KFM07B	81.10–145.71	2,175 kg/948 L	Packer	10 bars	2005-09-19
KFM07B	80.50–208.62	750 kg/330 L	Packer	32 bars	2005-09-16

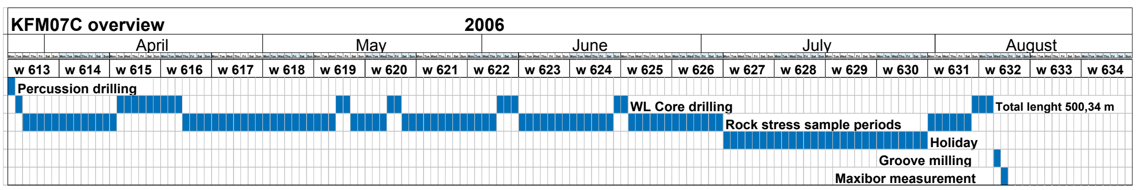


__Figure 5-8.__ Overview of the drilling performance of borehole KFM07B.

5.2.2 Geometrical and technical design of borehole KFM07C

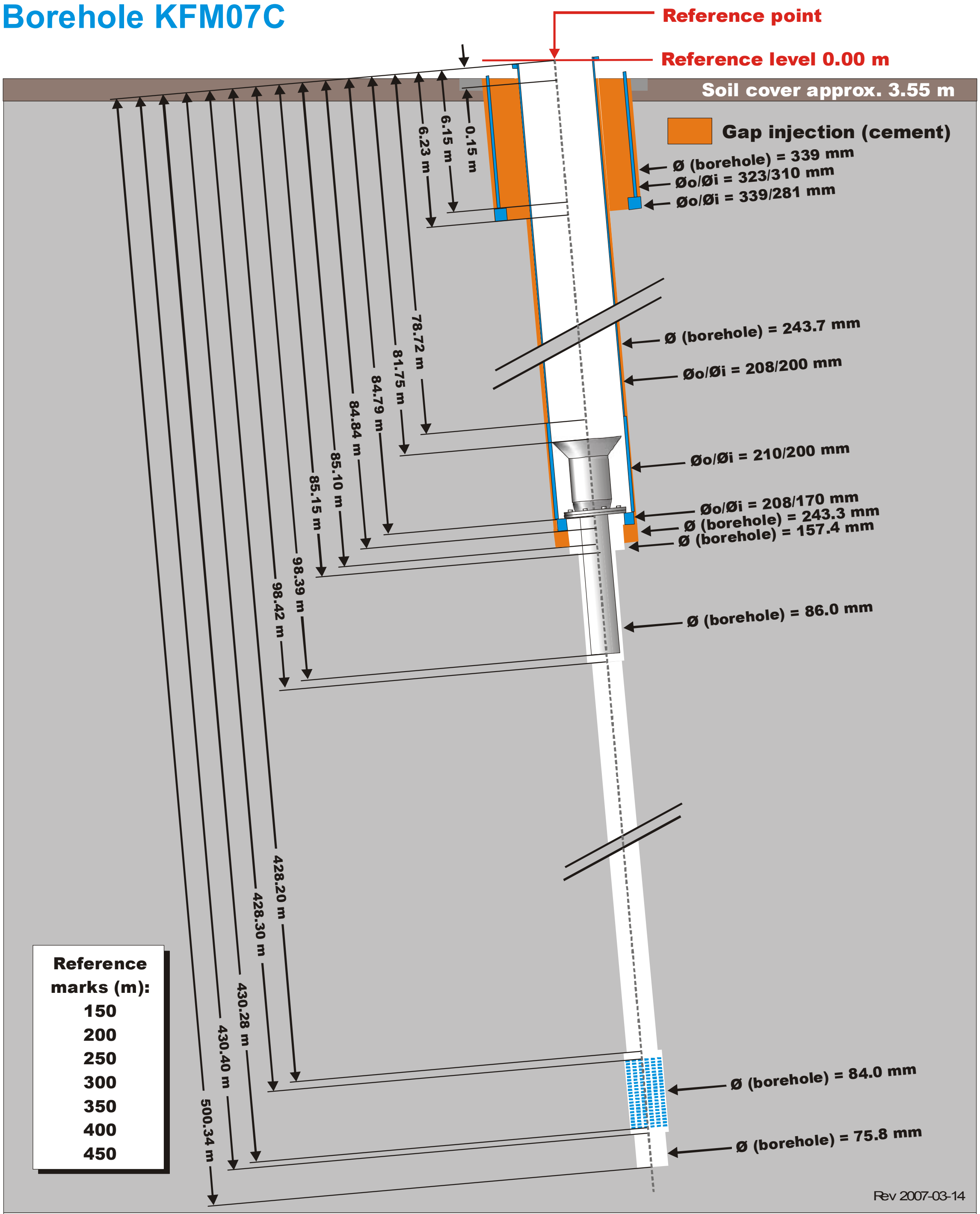
Administrative, geometric and technical data for the core drilled borehole KFM07C are presented in Table 5-9. The technical design of the borehole is illustrated in Figure 5-9.

Table 5-9. Administrative, geometric and technical data for borehole KFM07C.

Parameter	
Borehole name	KFM07C
Location	Forsmark, Östhammar municipality, Sweden
Drilling start date	December 20, 2005
Completion date	August 08, 2006
Drilling period	2005-12-20 to 2006-01-17 (0–85.15 m) 2006-03-30 to 2006-08-08 (85.15–500.34 m)
Contractor core drilling	Drillcon Core AB
Core drill rig	Atlas Copco Craelius B20
Position KFM07C at top of casing (RT90 2.5 gon V 0:–15 / RHB 70)	N 6700125.61 E 1631034.45 Z 3.35 (m. a. s. l.) Azimuth (0–360°): 142.71° Dip (0–90°): –85.40
Position KFM07C at bottom of hole (RT90 2.5 gon V 0:–15 / RHB 70)	N 6700083.70 E 161060.15 Z –494.56 (m. a. s. l.) Azimuth (0–360°): 143.85° Dip (0–90°): –84.24°
Borehole length	500.34 m
Borehole diameter and length	From 0 m to 6.23 m: 339 mm From 6.23 m to 85.10 m: 243.3 mm From 85.10 to 85.15 m: 157.4 mm From 85.15 m to 98.42 m: 86.0 mm From 98.42 m to 500.34 m: 75.8 mm Between 428.20–430.40 m: 84.0 mm
Casing diameter and length	$Ø_o/Ø_i$ = 323 mm/310 mm to 6.23 m $Ø_o/Ø_i$ = 208 mm/200 mm 0m to 84.84 m
Transition cone inner diameter* *Extended for stabilization	At 81.75 m: 0.195 m At 98.39 m: 0.080 m
Stabilized section with PLEX	428.30–430.28 m
Drill core dimension	85.15–500.34 m/Ø 51 mm
Core interval	85.15–500.34 m

Technical data

Borehole KFM07C



Drilling reference point
Northing: 6700125.61 (m), RT90 2,5 gon V 0:-15
Easting: 1631034.45 (m), RT90 2,5 gon V 0:-15
Elevation: 3.35 (m), RHB 70

Orientation
Bearing (degrees): 142.71°
Inclination (degrees): -85.40°

Borehole
Length: 500.34 m

Percussion drilling period
Drilling start date: 2005-12-20
Drilling stop date: 2006-01-17

Core drilling period
Drilling start date: 2006-03-30
Drilling stop date: 2006-08-08

Additional work
Reaming and PLEX setting 2006-08-15

Figure 5-9. *Technical data of borehole KFM07C.*

5.2.3 Percussion drilling section 0–85.15 m in KFM07C

Drilling

Drilling of the section 0–85.15 m was progressing between Dec 20th, 2005 and Jan 17th, 2006, and is presented in Figure 5-10. As mentioned in Section 4.4.2, the upper part to 6.23 m of the borehole was drilled and cased according to NO-X 281. Based on experience from the nearby boreholes KFM07A and KFM07B, respectively, the highly fractured sections at c. 50 m vertical depth had to be penetrated during the pilot drilling with dimension Ø 157.4 mm, but no large water inflow was encountered. The borehole was extended to 85.15 m and thereafter reamed to 243.7 mm and cased with a Ø 200/208 mm stainless steel casing to 84.84 m. Finally, the gap between the casing and the borehole wall was cement grouted, so that the water inflow ceased completely.

Measurements while drilling

During, and immediately after drilling, a program for sampling and measurements was applied, cf. Section 4.1. Some of the results are displayed in the Well Cad-presentation in Appendix B (deviation measurements, penetration rate and rock type distribution), whereas other results (flow data and electrical conductivity) are used only as supporting data for on-site decisions.

5.2.4 Core drilling of section 85.15–500.34 m in borehole KFM07C

Drilling

After the percussion drilling, a break followed until the drilling of the section 85.15–500.34 m commenced on March 30th and continued to August 8th, 2006 (Figure 5-11).

The experience from drilling KFM07A and KFM07B at DS7 confirmed the previous interpretation of the fracture characteristics of the Forsmark tectonic lens. The shallow parts of the bedrock are much more fractured and water yielding than the deeper parts. Also in KFM07C

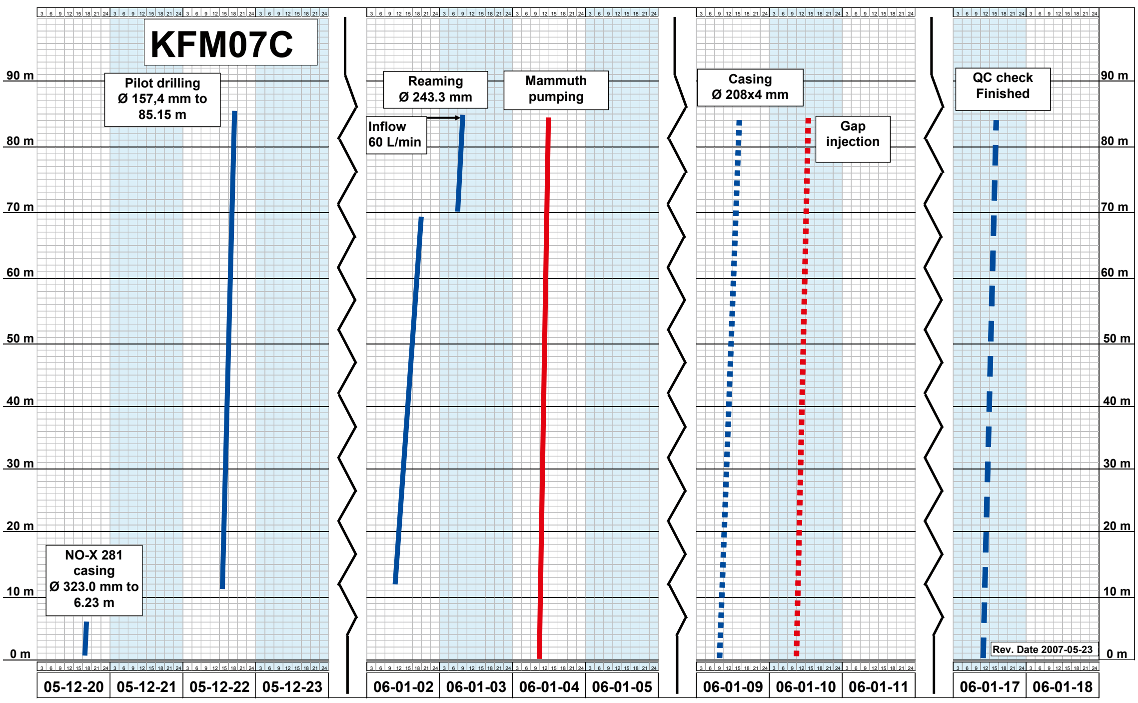


Figure 5-10. *Percussion drilling progress (depth and activity versus calendar time).*

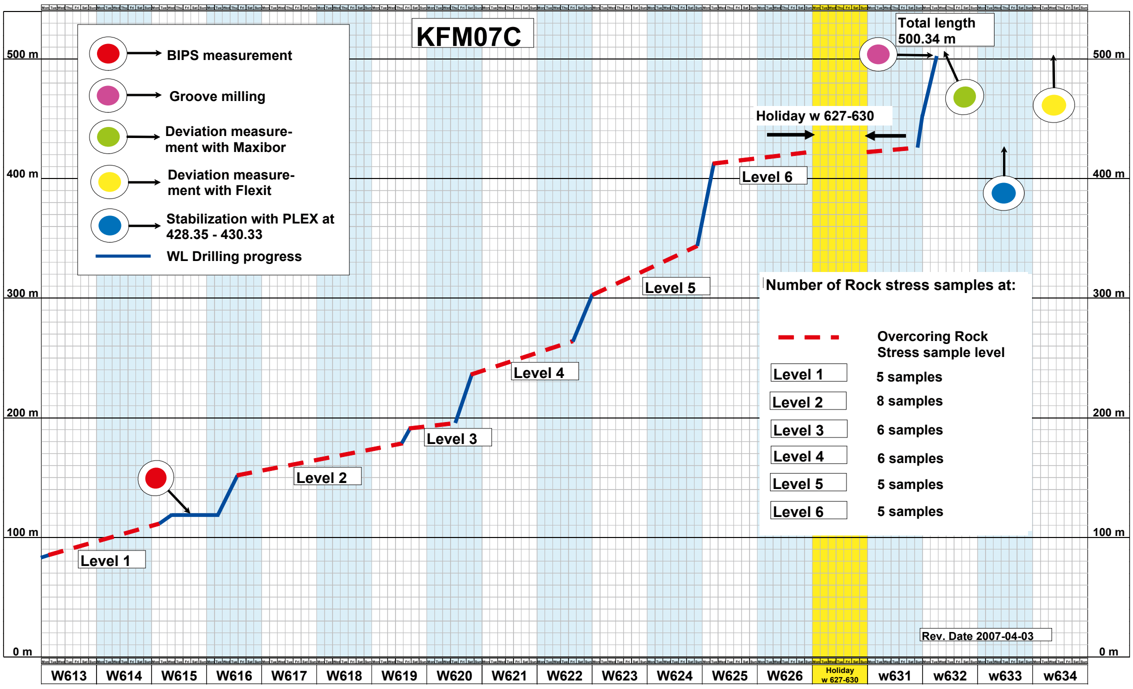


Figure 5-11. Core drilling progress KFM07C (length versus calendar time). The diagram is also showing the logistics for rock stress measurement (overcoring) levels, groove milling, deviation measurements, BIPS-surveys, and borehole stabilization.

fractured rock prevailed to c. 150 m drilling length. When the overcoring stress measurement started at level 1, just below the casing, a water inflow at c. 93 m drilling length was encountered, and in combination with fractured rock, also several broken pilot cores were retrieved. Arguments were brought up in favour of cement grouting the fractured rock section in order to decrease the inflow. During the Eastern, drilling and measurements were interrupted, where after a BIPS-survey in section 85–129 m was performed. Before resuming the measurements the borehole section from 86.75 m to 98.42 m was reamed to 86 mm and a temporary casing shield off the zone.

At the same time, a newly developed equipment for nitrogen flushing became available. The lower end of the gas supply hose is supplied with a nozzle, designed to fit into the pilot borehole. A large groundwater inflow enables flushing the borehole frequently with a mixture of nitrogen gas and groundwater, which considerably improves the possibility of cleaning the pilot hole as well as the rest of the borehole. To sum up, it was judged as more promising to obtain good stress measurement results by retaining the water inflow to supply frequent nitrogen flushing in order to support the installation and gluing of the measurement cells.

The rock stress measurements now continued, and were performed at five levels, levels 2 to 6, between 152–426 m. The frequency of core discing of the overcored hollow drill cores increased versus depth. When the drilling and measurements after the summer holidays were resumed at 421m, core discing occurred in all three overcoring samples, and therefore the measurement campaign was terminated at 426 m borehole length. The borehole was then drilled to 500.34 m, and before removing the drilling rig, an instable amphibolitic dyke was reinforced with a perforated steel plate between 428.35 and 430.33 m, see also Section 5.2.6.

Core sampling KFM07C

A preliminary on-site core logging was performed continuously.

Rock stress measurement KFM07C

During the period March 30th, 2006 to August 6th, 2006, overcoring stress measurements were conducted in the inclined borehole KFM07C, with the three-dimensional *Borre* probe. Measurements were attempted at six levels in the borehole, 85.15–110.13 m, 152.49–179.34 m, 192.29–197.88 m, 237.89–263.98 m, 303.99–341.34 m and 410.40–426.38 m. Due to the character of the stress field with high deviatory stresses, several measurement attempts failed, especially at larger depths, because of microfracturing in the overcored rock samples. The gluing problem, which was very disturbing in KFM07B, was however much reduced in KFM07C. The overcoring measurements in borehole KFM07C are presented in /5/.

5.2.5 Measurements while drilling KFM07C

During, and immediately after drilling, a pro gram for sampling and measurements was applied, cf. Section 4.4.3. Some of the results are displayed in the Well Cad-presentation in Appendix B (deviation measurements, penetration rate and rock type distribution), whereas other results (flow data and electrical conductivity) are only used as supporting data for on-site decisions. Below, the results of the water balance, Uranine content, groove milling and deviation measurements made after completed drilling of KFM07C are commented on.

Flushing water and return water flow rate – water balance KFM07C

The return water/flushing water balance was determined in borehole KFM07C by measuring and comparing the amounts of water pumped from the borehole respectively into it. A flow gauge in the measurement station, registered the flushing water flow rate, se Figure 3-6. The return water was measured by another flow meter, mounted on–line the discharge pipeline, see Figure 3-6.

Figure 5-12 displays the accumulated volumes of flushing water respectively return water from the entire drilling period (results from Uranine measurements are presented below). From the accumulated volumes of flushing water and return water at the end of the drilling period the return water/flushing water quotient may be calculated, in this case resulting in the quotient 5.61. The high quotient is an effect of the major efforts that were made for cleaning and flushing the borehole. Also the high water inflow in the upper section (93 m) and the long drilling and measurement period between February and August 2006 had a great impact on the water balance quotient.

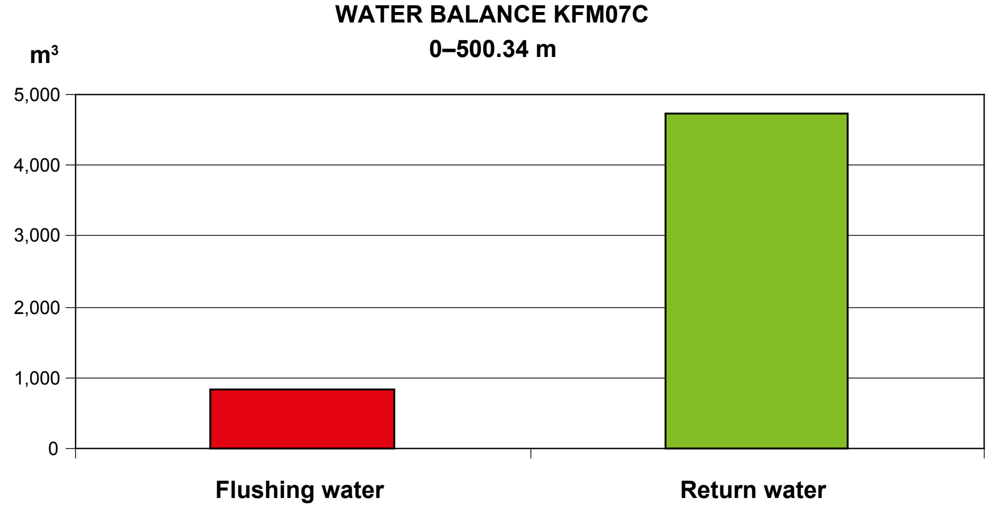


Figure 5-12. *The total volume of flushing water used during core drilling of KFM07C was 843 m^3. During the same period, the total volume of return water was 4,730 m^3. The return water/flushing water balance is then 5.61, i.e. much exceeding 1.0 due to a major inflow of groundwater in the highly fractured section at 93–150 m.*

Uranine content of flushing water KFM07C

During the drilling period, sampling of flushing water and analyses of the tracer content were performed systematically with a frequency of approximately one sample per 20–30 m drilling length, except in section 200–350 m were no samples were collected, see Figure 5-13. Like in all previously drilled boreholes, except KFM01A, a dosing feeder controlled by a flow meter was used for labelling the flushing water with a Uranine concentration of 0.2 mg/L. The concentration of Uranine was stable except at three occasions. According to notations in the log book, the amount of Uranine added to the borehole was 190 g. If the average Uranine concentration values in the flushing water and in return water are used to calculate the amount of Uranine provided to and recovered from the borehole, the calculations give 170 g, and 248 g respectively. Obviously the calculations are associated with some uncertainty, since the amount of Uranine added to the hole seems lower than that recovered. It is however plausible that most of the added Uranine was recovered.

On the other hand, when comparing the amounts of Uranine supplied to the other two boreholes at DS7, (see Table 5-10), a different explanation can be found. In KFM07A there is a significant loss of Uranine, 74 g, calculated from the difference between the Uranine amount added to the borehole and the calculated Uranine amount in the return water. Also in borehole KFM07B, there is probably a considerably large amount of Uranine loss, as no mammoth pumping is used in traditional core drilled boreholes.

The drilling at DS7 has also confirmed the occurrence of sub-horizontal water-yielding fracture zones in the upper part of the bedrock. It is therefore reasonable to believe that most of the loss of Uranine from KFM07A and KFM07B was recovered during drilling and pumping in KFM07C, which would explain the high value of recovered Uranine from that borehole.

Table 5-10. Amount of Uranine added to and recovered from boreholes KFM07A, KFM07B and KFM07C drilled at DS7.

Borehole	Uranine doser [g]	Uranine in, calculated [g]	Uranine out, calculated [g]	Mass balance [%]	Comments
KFM07A	255	239	181	2.05	
KFM07B	122.65	–	–	1.53	Not a telescopic borehole
KFM07C	190	170	248	5.61	

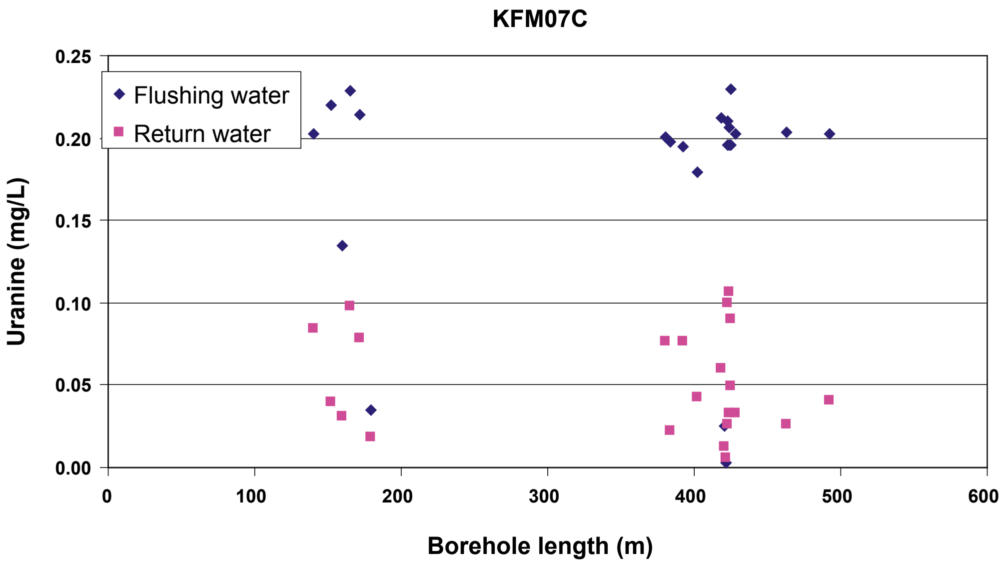


Figure 5-13. *Uranine content versus drilling length in flushing water during drilling of borehole KFM07C.*

Groove milling KFM07C

A compilation of length to the reference grooves and if they where detected is given in Table 5-11. The positions of the grooves are determined from the length of the drilling pipes used at the milling process. The length is measured from the upper part of the upper two grooves.

Recovery of drill cuttings

The theoretical volume of the percussion drilled and reamed part of the borehole (0–85 m) is c. 4.25 m^3. Weighing of drill cuttings and comparison with the weight of the theoretical volume was not carried out due to the relatively high water flow. This caused an uncontrolled overflow of return water with suspended drill cuttings, making it difficult to obtain reliable results of drill cuttings estimations. However, it seems probable that the percussion drilled part was well cleaned from debris, since casing driving and gap grouting to full borehole length worked well, without obstruction from settled drill cuttings.

The theoretical difference in volume of the core drilled part of KFM07C and the drill core is calculated to be 1.042 m^3. This volume should correspond to the amount of drill cuttings produced during drilling. If a density of 2,650 kg/m^3 (approximate figure for granitites in the Forsmark area) is applied, the total weight of the theoretical amount of debris is estimated at 2,761 kg. The calculated dry weight of the debris from the core drilling recovered and weighed in the containers is 2,311 kg. The difference between the theoretically produced and recovered dry weight of debris is 450 kg, which gives a recovery of 84%.

The recovery figure could be commented on. The dwell time in the container system is too short for sedimentation of the suspended finest fractions. No estimation was made of the amount of suspended material, but the true recovery is probably somewhat higher than 84%. It should also be observed, that weighing of the container including water and debris is associated with some uncertainty.

However, it seems plausible that some drilling debris has been injected into the fracture system of the formation, especially in the permeable sections with increased fracture frequency above c. 150 m in the borehole.

Deviation measurements in KFM07C

The principles of the equipment for deviation measurements were explained in Section 3.1.6. Also the changed strategy for deviation measurements during the site investigations was commented on, including the fact that the FLEXIT-method is now the principal method applied for deviation measurements, also in borehole KFM7C. As mentioned in Section 5.1.5, when MAXIBOR™-measurements or deviation measurements with some other method have been performed as well, these are used for uncertainty determinations of the deviation measurements, if the measurements are technically successful.

Table 5-11. Reference grooves in KFM07C.

Reference groove at (m)	Detection with the SKB level indicator	Confirmed from BIPS	Reference groove at (m)	Detection with the SKB level indicator	Confirmed from BIPS
150	Yes	Yes	350	Yes	Yes
200	Yes	Yes	400	Yes	Yes
250	Yes	Yes	450	Yes	Yes
300	Yes	Yes			

The quality control program of deviation measurements was described in Section 5.1.5. The magnetic field variation during August 22th and November 8th, 2006, is shown in Figure 5-14 and Figure 5-15 and displays only minor disturbances when the FLEXIT-survey in KFM07C was performed.

In the following a systematic description of the construction of the revised deviation data for borehole KFM07C is given.

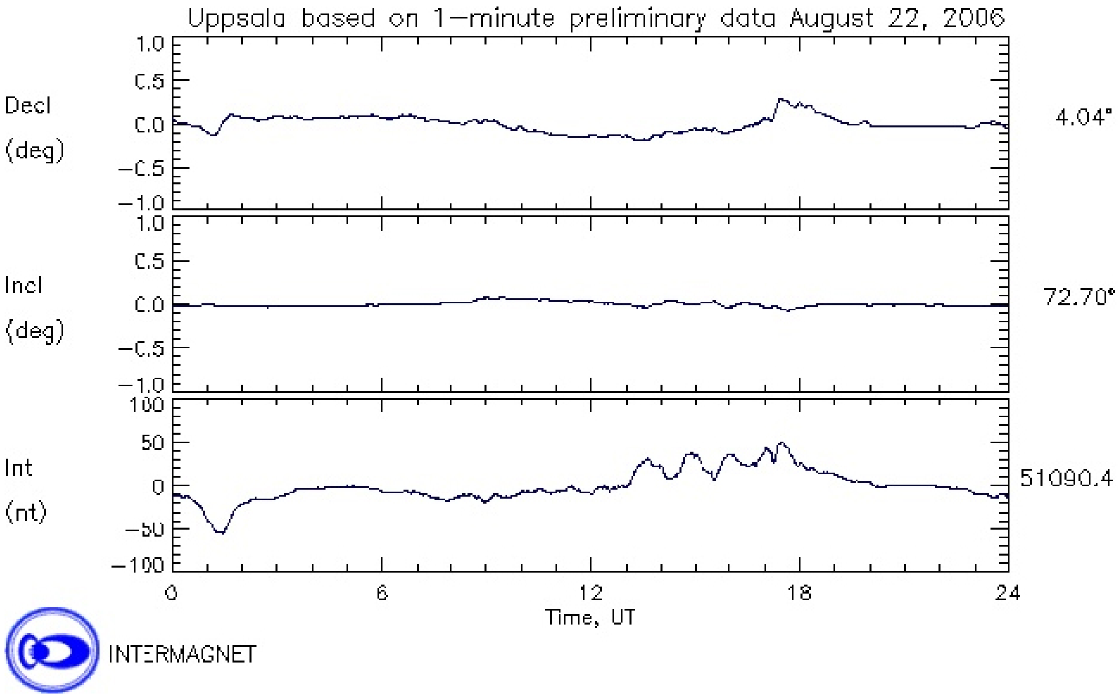


__Figure 5-14.__ Magnetic field variation during the FLEXIT-survey performed on August 22th, 2006.

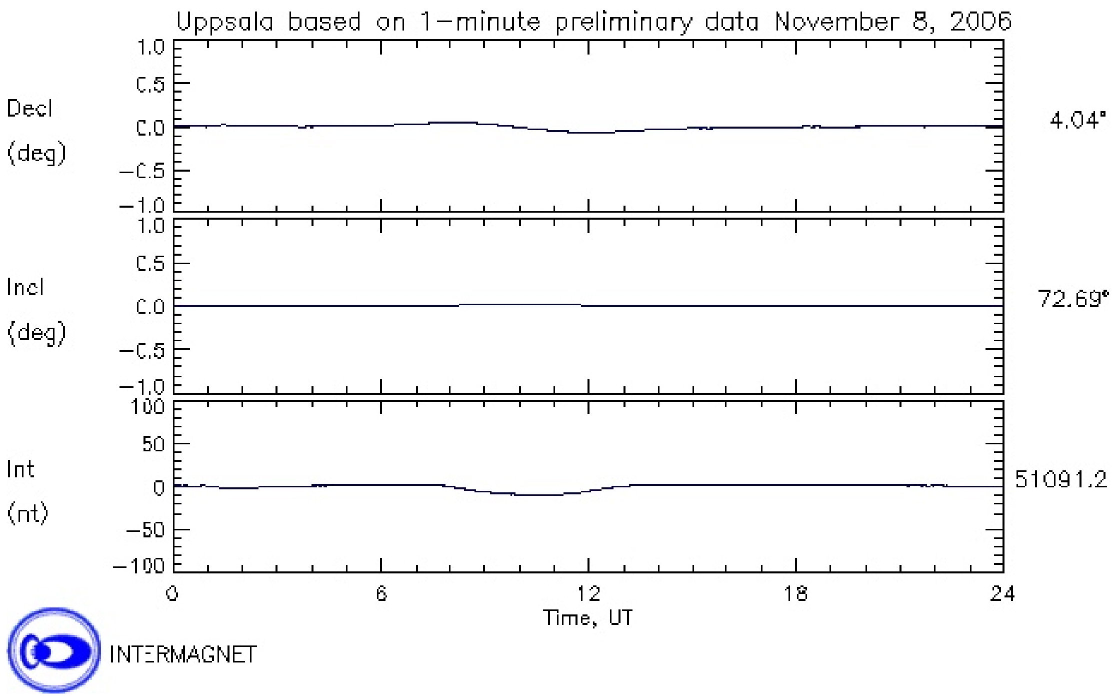


__Figure 5-15.__ Magnetic field variation during the FLEXIT-survey performed on November 8th, 2006.

The data approved are one Reflex MAXIBOR™-logging to 498 m and three FLEXIT-loggings to 498 m, see Table 5-12. With the FLEXIT Smart Tool System, the deviation measurements performed in borehole KFM07C were two surveys carried out with measurements every 3 m downwards, and one measurement at every 50 m upwards. The two surveys downwards, with activity numbers 13132004 and 13135314, provided almost repeatable results, and were therefore chosen for the construction of the EG154 deviation file to be “in use displayed” in Sicada (see explanation in Section 3.1.6). This file is designated as EG154.

The EG154-activity presented in Table 5-13 specifies the deviation measurements used in the resulting calculation. The bearing measurements start at 96 m and 102 m respectively, so that the magnetometer should not be effected by the 85 m steel casing.

A subset of the resulting deviation file together with the estimated radius uncertainty is presented in Table 5-14.

Table 5-12. Activity data for the four deviation measurements approved for KFM07C. The two magnetic-accelerometer measurements with activity numbers 13132004 and 13135314 were used for calculation of a final borehole deviation, whereas all four measurements were used for calculation of the uncertainty.

Activity Id	Activity Type code	Activity	Start Date	Idcode	Secup (m)	Seclow (m)	Flags
13118511	EG156	MAXIBOR-measurement	2006-08-09 14:00	KFM07C	3	498	F
13132004	EG157	Magnetic-accelerometer measurement	2006-08-22 15:45	KFM07C	3	498	CF
13132005	EG157	Magnetic-accelerometer measurement	2006-08-22 17:40	KFM07C	3	498	CF
13135314	EG157	Magnetic-accelerometer measurement	2006-11-08 07:10	KFM07C	3	498	CF
13141376	EG154	Borehole deviation multiple measurements	2006-12-05 12:00	KFM07C			I C

Table 5-13. Content of the EG154 file (multiple borehole deviation intervals).

Deviation Activity id	Deviation Angle type	Approved Secup (m)	Approved Seclow (m)
13132004	Bearing	96	498
13132004	Inclination	3	498
13135314	Bearing	102	498
13135314	Inclination	3	498

Table 5-14. Deviation data from KFM07C from every approx. 100 m vertical length calculated from EG154. Inclination, bearing and radius uncertainty are also included.

Borehole	Length (m)	Northing (m)	Easting (m)	Elevation (m)	Inclination (degrees)	Bearing (degrees)	Inclination uncertainty	Bearing uncertainty	Radius uncertainty
KFM07C	0	6700125.613	1631034.452	3.351	–85.33	142.71	0.306	3.36	0
KFM07C	105	6700116.882	1631039.739	–101.146	–83.68	154.3	0.306	3.36	0.609
KFM07C	204	6700107.332	1631044.497	–199.569	–83.91	152.31	0.306	3.36	1.234
KFM07C	306	6700097.878	1631049.365	–301.013	–84.1	152.31	0.306	3.36	1.857
KFM07C	405	6700088.998	1631054.177	–399.497	–84.155	150.075	0.306	3.36	2.449
KFM07C	500.34	6700080.826	1631059.25	–494.35	–84.22	146.545	0.306	3.36	3.013

The calculated deviation (EG154-file) in borehole KFM07C shows that the borehole deviates slightly upwards and slightly to the left with an absolute deviation of 13 m compared to an imagined straight line following the dip and strike of the borehole start point (Figure 5-16). “Absolute deviation” and “radius uncertainty” are explained in Section 5.1.5.

Consumables

The special type of thread grease (silicon based) used in this particular borehole was certified according to SKB MD 600.006, Version 1.0, Instruction for the use of chemical products and material during drilling and surveys. Oil and grease consumptions are given in Table 5-15 below.

The amount and quality of grout for sealing the casing gap and tighten the borehole are reported in Table 5-16 below.

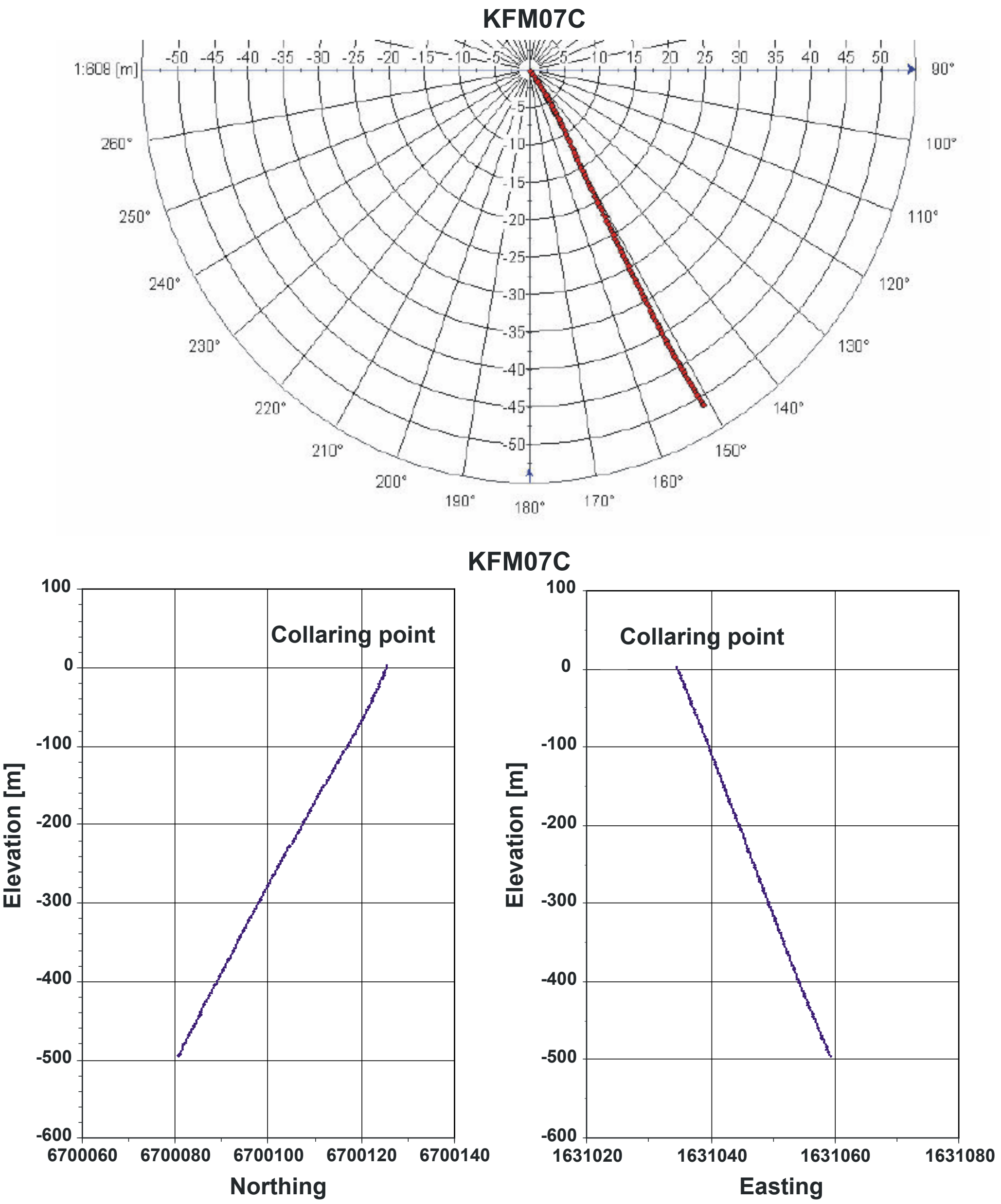


Figure 5-16. *Upper figure is a horizontal projection and lower figures are two vertical projections of the measured deviation in KFM07C.*

Table 5-15. Grease, oil and diesel consumption KFM07C.

Borehole ID	Thread grease Üni Silikon L50/2	Grease for the drilling machine Statoil AB	Engine oil Castrol Tection 15W-40	Hydraulic oil Premium ECO HT-E 46	Diesel engines OKQ8 Diesel miljöklass 1
KFM07C	6.5 kg	0.8 kg	Estimated 30 L	50 L	20,475 L

Table 5-16. Cement consumption KFM07C.

Borehole ID	Grouting length (m)	Cement volume (Aalborg Portland Cement/microsilica)	Grouting method	Remarks (Final pressure)	Date
KFM07C	0.00–84.77	1,476 kg/1,435 L	Gap	Not registrated	2006-01-10
KFM07C	0.80–0.15	72 kg/70 L	Hose		2006-01-17

5.2.6 Stabilization in KFM07C

Ensuing completion of drilling of a borehole at the site investigation, an extensive borehole measurement programme is conducted. When drilling in KFM07C a fractured and soft amphibolitic dyke was penetrated at c. 428 m, see Figure 5-17. As the borehole is almost vertical and located close to the central area were the ramp and underground maintenance facilities are planned to be located, it was decided to stabilize the dyke to secure that a complete measurement programme could be performed in KFM07C.

It was decided to use the developed PLEX-system described in Section 3.1.8 for stabilization of the borehole wall in KFM07C. The following sequence of actions was taken (cf. Figures 3-8 and 5-18):

- The instable section between 428.20–430.40 was reamed to 84 mm.
- The PLEX tool supplied with one perforated stainless steel plate was attached to the drill pipe string and lowered into the borehole.
- The packer was inflated with an excess pressure of between 60–70 bars whereby the perforated stainless steel plate was forced into the reamed part of the borehole wall.
- The packer was deflated whereafter the tool was retrieved from the borehole.

Figure 5-17. Image of instable section in borehole KFM07C.

After the PLEX-operation, the entire borehole was logged with the BIPS-camera, see Figure 5-18. The video images show that the perforated plate was expanded in the reamed section without any damages.

After the PLEX-stabilization, the borehole has been possible to investigate without problems with instrument jamming. Because the steel plate is perforated, it is also possible to perform hydraulic tests in the entire borehole.

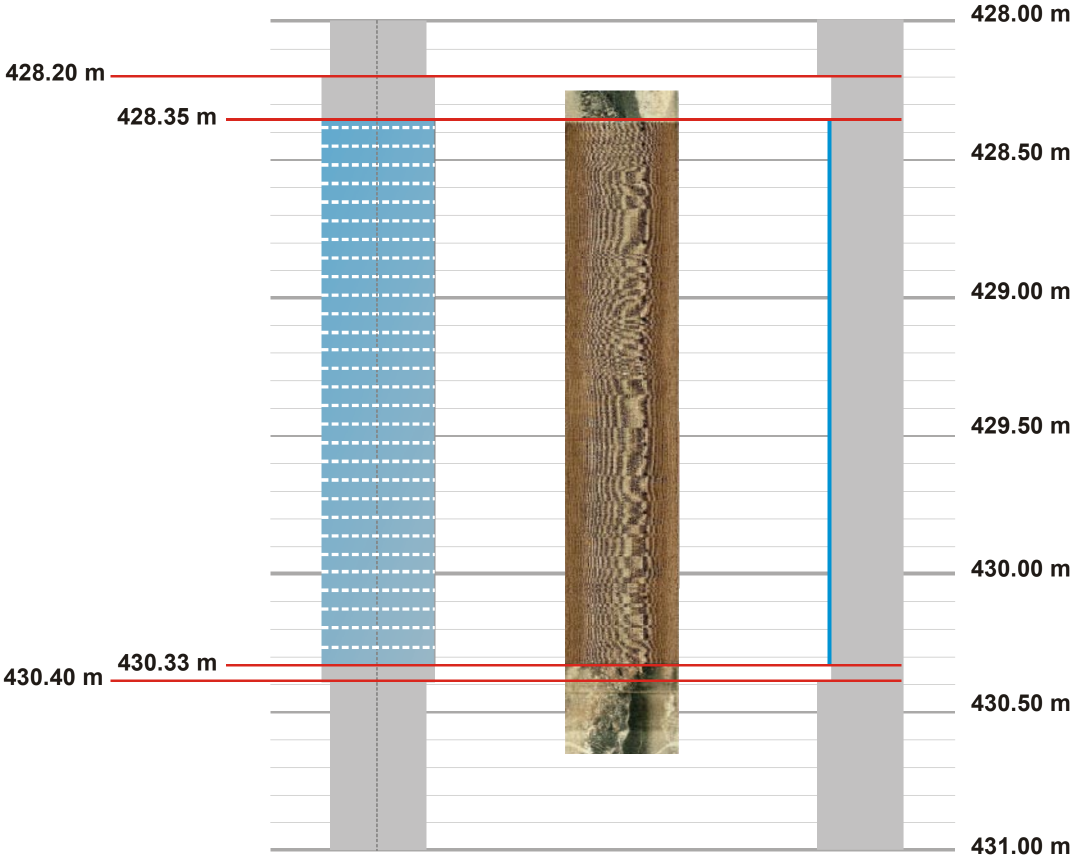


Figure 5-18. *Schematic figure of the stabilized section in borehole KFM07C with BIPS-images of the borehole section after stabilization with the PLEX-system.*

References

/1/ **Claesson L-Å, Nilsson G, 2005.** Forsmark site investigation. Drilling of the telescopic borehole KFM07A at drill site DS7. SKB P-05-142, Svensk Kärnbränslehantering AB.

/2/ **Claesson L-Å, Nilsson G, 2004.** Forsmark site investigation. Drilling of two flushing water wells, HFM21 and HFM22, one groundwater monitoring well in solid bedrock, HFM20 and one groundwater monitoring well in soil, SFM0076. SKB P-04-245, Svensk Kärnbränslehantering AB.

/3/ **Petersson J, Skogsmo G, Wängnerud A, Berglund J, Stråhle A, 2005.** Forsmark site investigation. Boremap mapping of telescopic drilled borehole KFM07A. SKB P-05-105, Svensk Kärnbränslehantering AB.

/4/ **Sjöberg J, 2006.** Forsmark site investigation. Overcoring rock stress measurements in borehole KFM07B. SKB P-06-93, Svensk Kärnbränslehantering AB.

/5/ **Lindfors U, Perman F, Berg S, 2006.** Forsmark site investigation. Overcoring rock stress measurements in borehole KFM07C. SKB P-report in progress, Svensk Kärnbränslehantering AB.

/6/ **Döse C, Samuelsson E, 2006.** Boremap mapping of core drilled borehole KFM07B. Forsmark site investigation. SKB P-06-80, Svensk Kärnbränslehantering AB.

/7/ **Petersson J, Andersson U B, Berglund J, 2006.** Boremap mapping in telescopic drilled borehole KFM07C. Forsmark site investigation. SKB P-06-205, Svensk Kärnbränslehantering AB.

Well cad presentation of the core drilled borehole KFM07B

Title KFM07B

Svensk Kärnbränslehantering AB

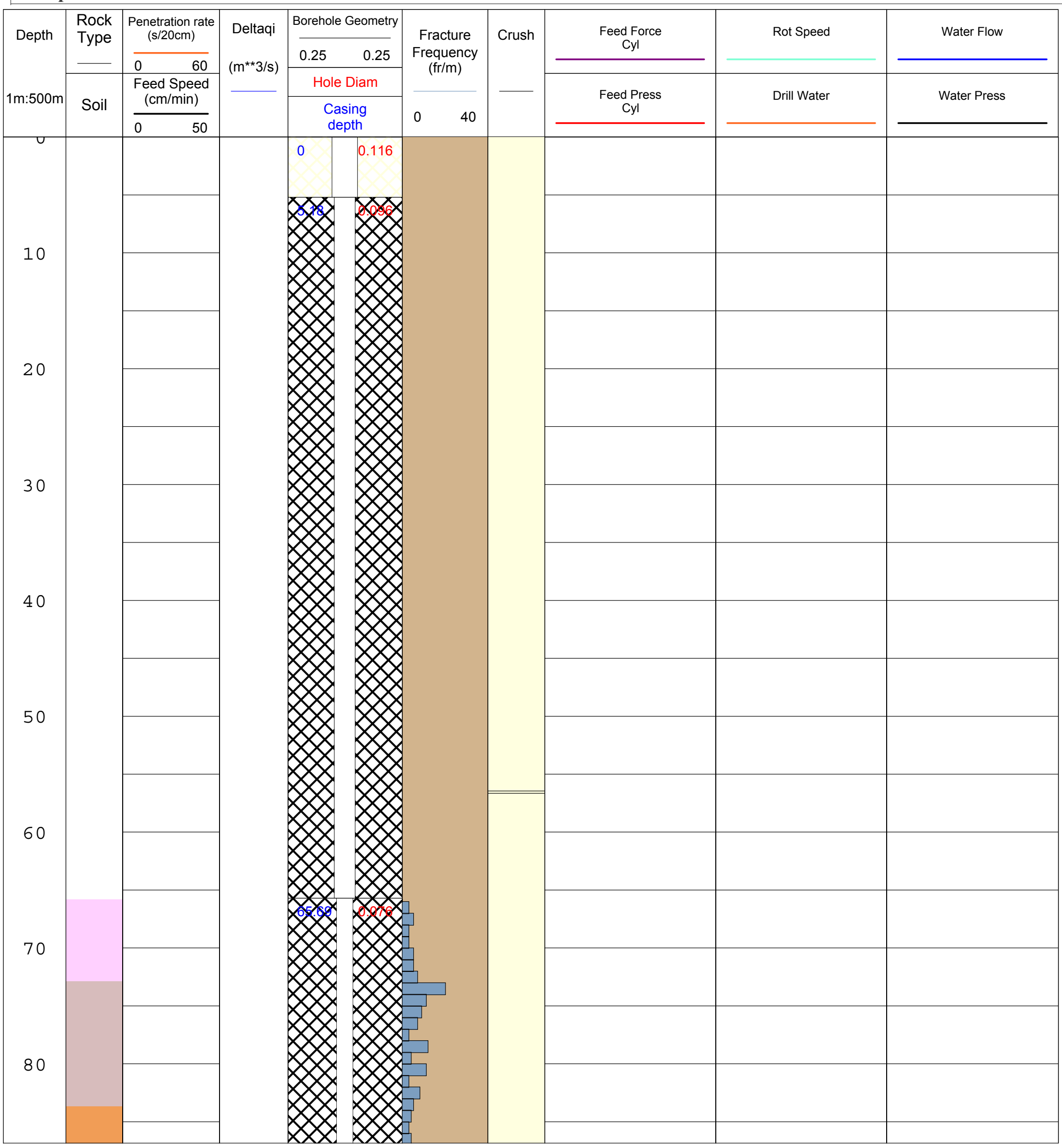
Site	FORSMARK	**Signed data**	
Borehole	KFM07B	**Coordinate System**	RT90-RHB70
Diameter [mm]	76	**Northing [m]**	6700123.62
Length [m]	298.93	**Easting [m]**	1631036.83
Bearing [°]	134.35	**Elevation [m.a.s.l.]**	3.36
Inclination [°]	-53.71	**Drilling Start Date**	2005-05-30 16:20:00
Date of mapping		**Drilling Stop Date**	2005-10-18 10:24:00
		Plot Date	2006-08-27 21:13:11

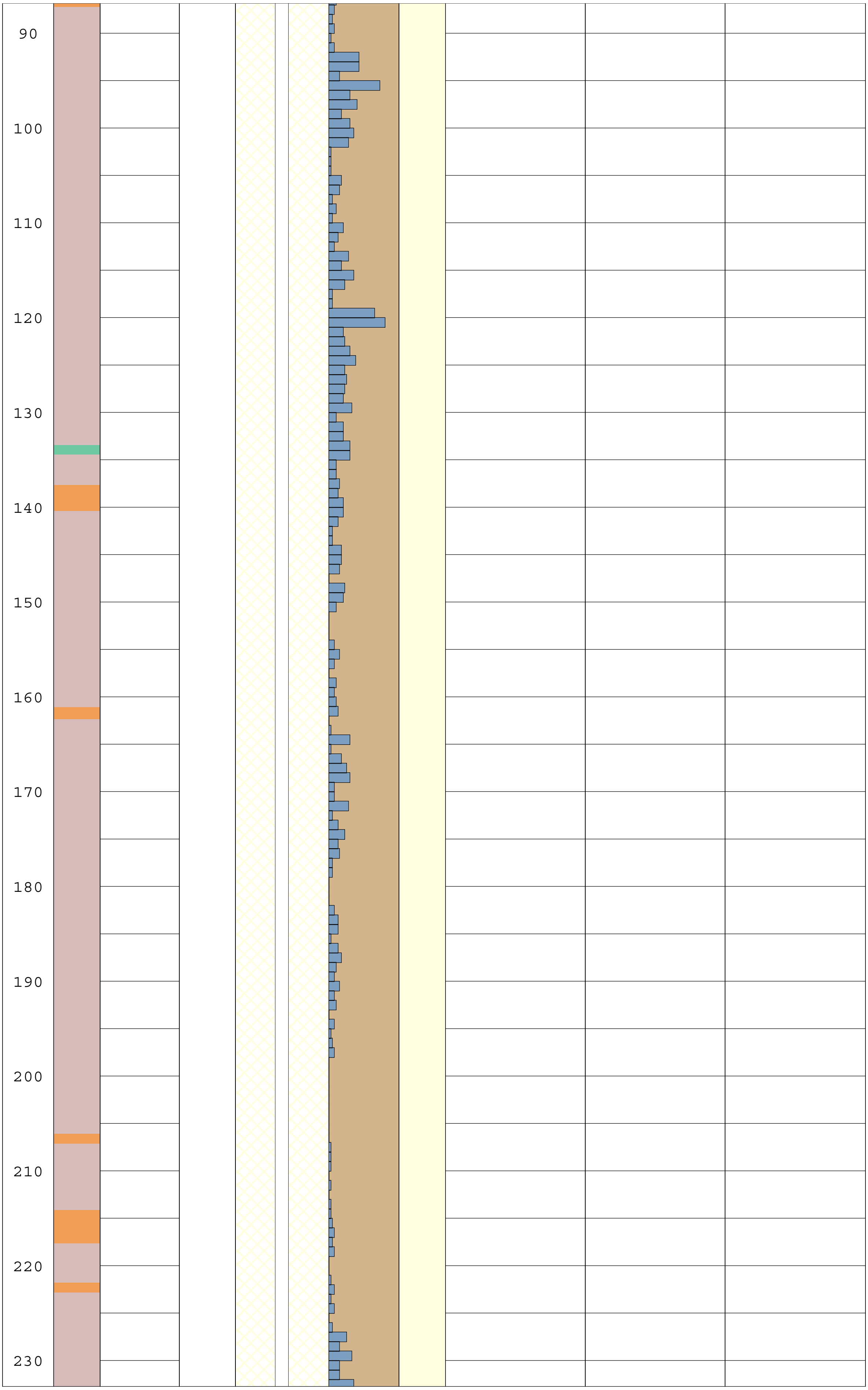
ROCKTYPE FORSMARK

SOIL

- **Pegmatite, pegmatitic granite**
- **Granite, granodiorite and tonalite, metamorphic, fine- to medium-grained**
- **Granite to granodiorite, metamorphic, medium-grained**
- **Amphibolite**

Script Name

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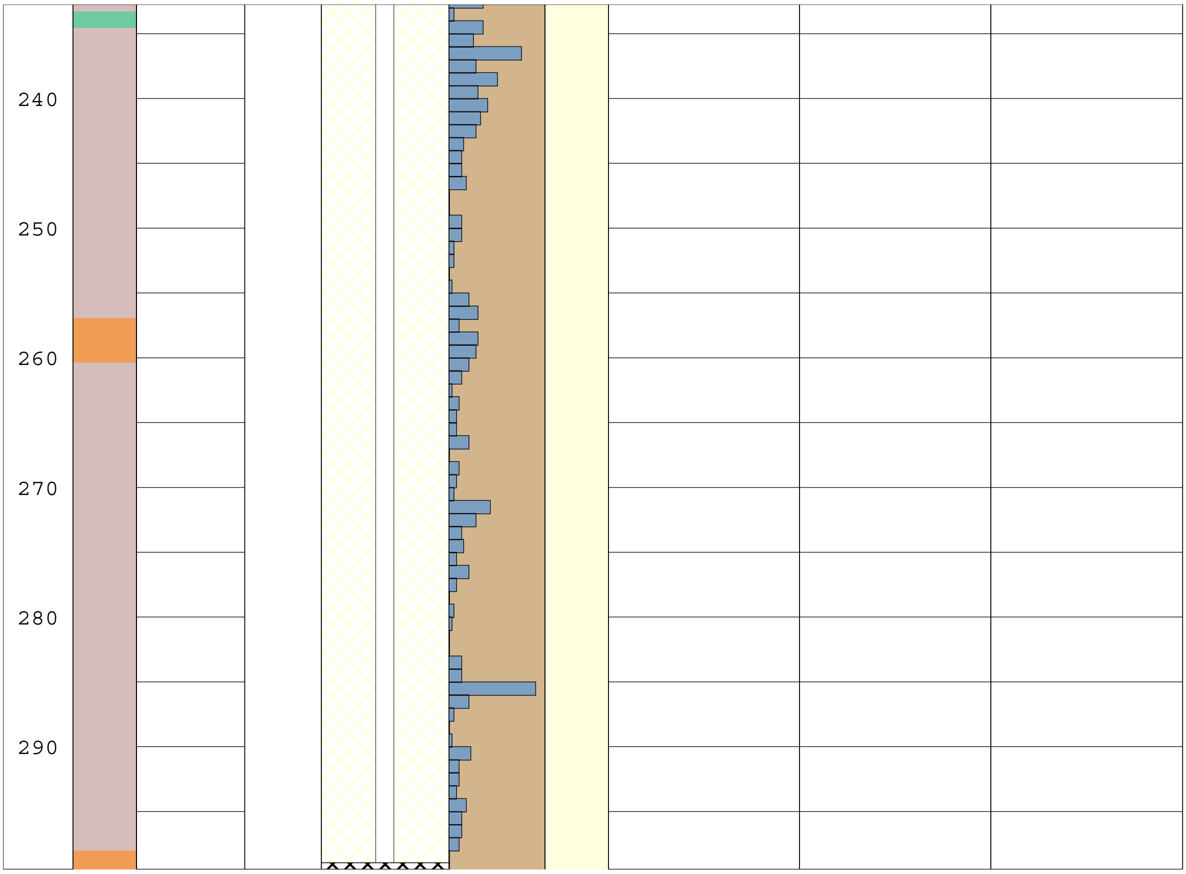
100
110
120
130
140
150
160
170
180
190
200
210
220
230



240
250
260
270
280
290

Appendix B

Well cad presentation of the core drilled borehole KFM07C

Title KFM07C

Svensk Kärnbränslehantering AB

Site	FORSMARK	**Signed data**	
Borehole	KFM07C	**Coordinate System**	RT90-RHB70
Diameter [mm]	76	**Northing [m]**	6700125.61
Length [m]	500.34	**Easting [m]**	1631034.45
Bearing [°]	142.71	**Elevation [m.a.s.l.]**	3.35
Inclination [°]	-85.40	**Drilling Start Date**	2005-12-20 14:30:00
Date of mapping		**Drilling Stop Date**	2006-08-08 13:00:00
		Plot Date	2007-04-16 23:13:54

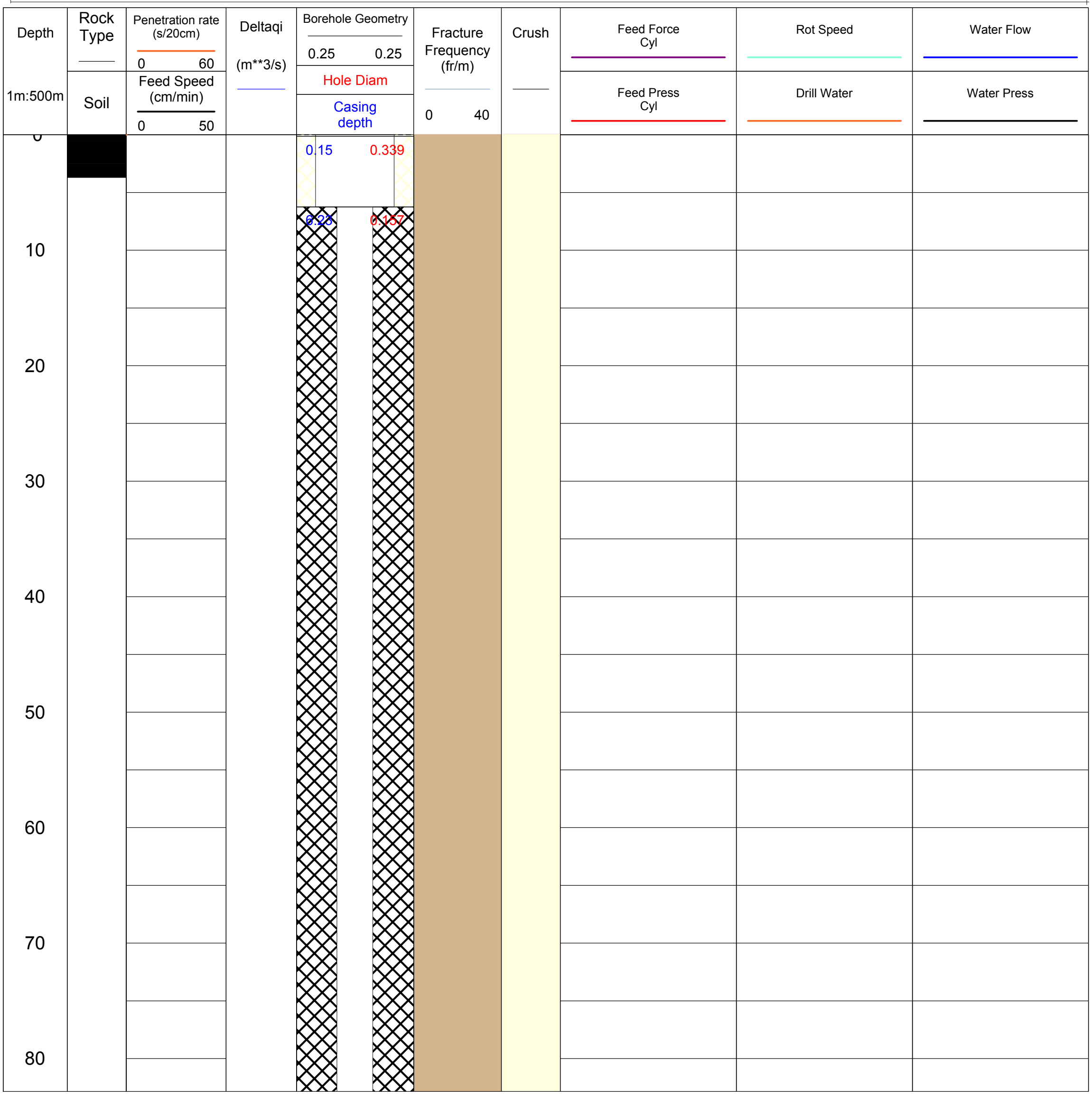
ROCKTYPE FORSMARK

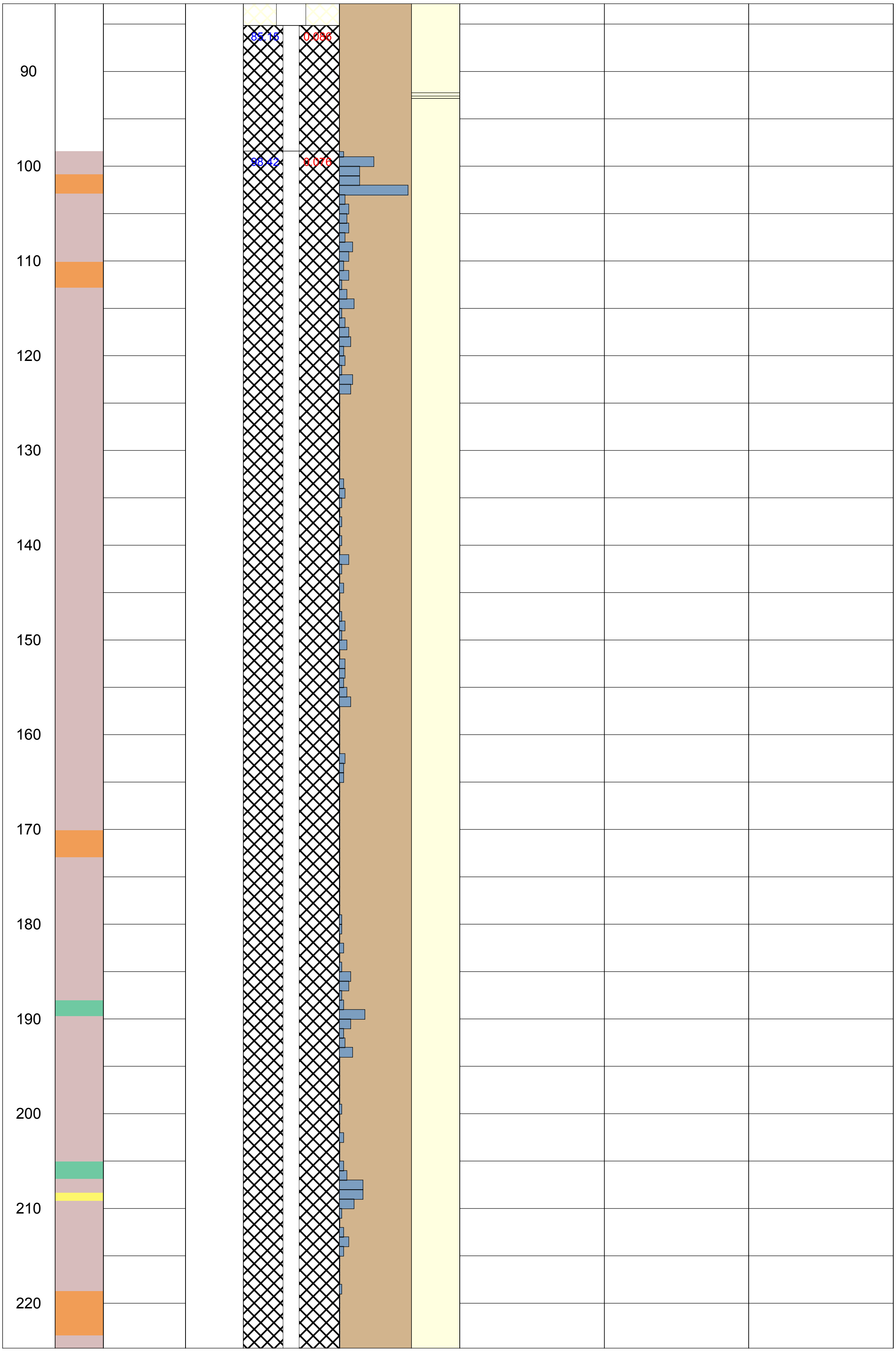
- **Pegmatite, pegmatitic granite**
- **Granite, granodiorite and tonalite, metamorphic, fine- to medium-grained**
- **Granite to granodiorite, metamorphic, medium-grained**
- **Diorite, quarts diorite and gabbro, metamorphic**
- **Amphibolite**
- **Felsic to intermediate volcanic rock, metamorphic**

SOIL

- **Soil**

Script Name





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100
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130
140
150
160
170
180
190
200
210
220
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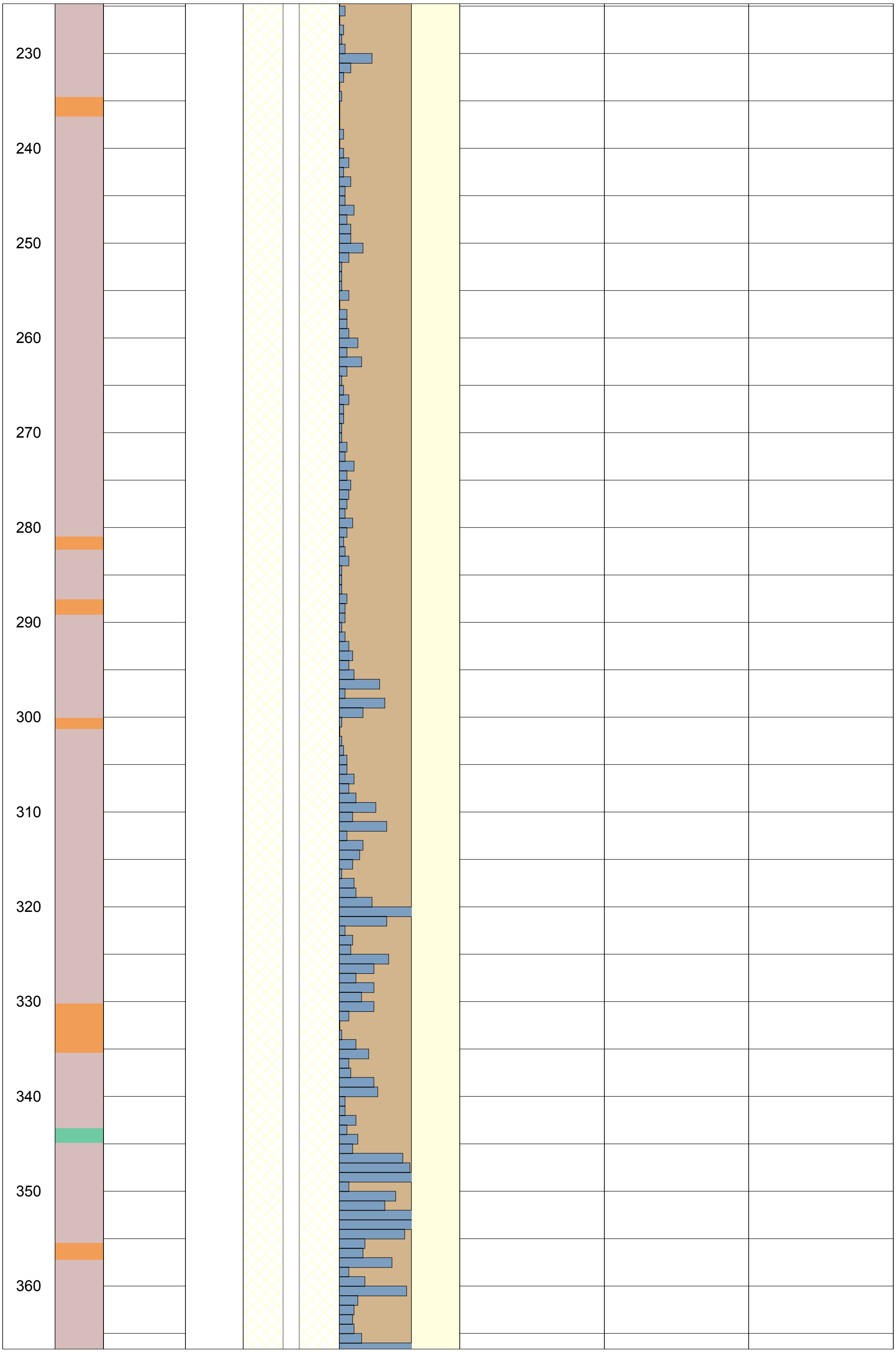
0.086
98.42
0.076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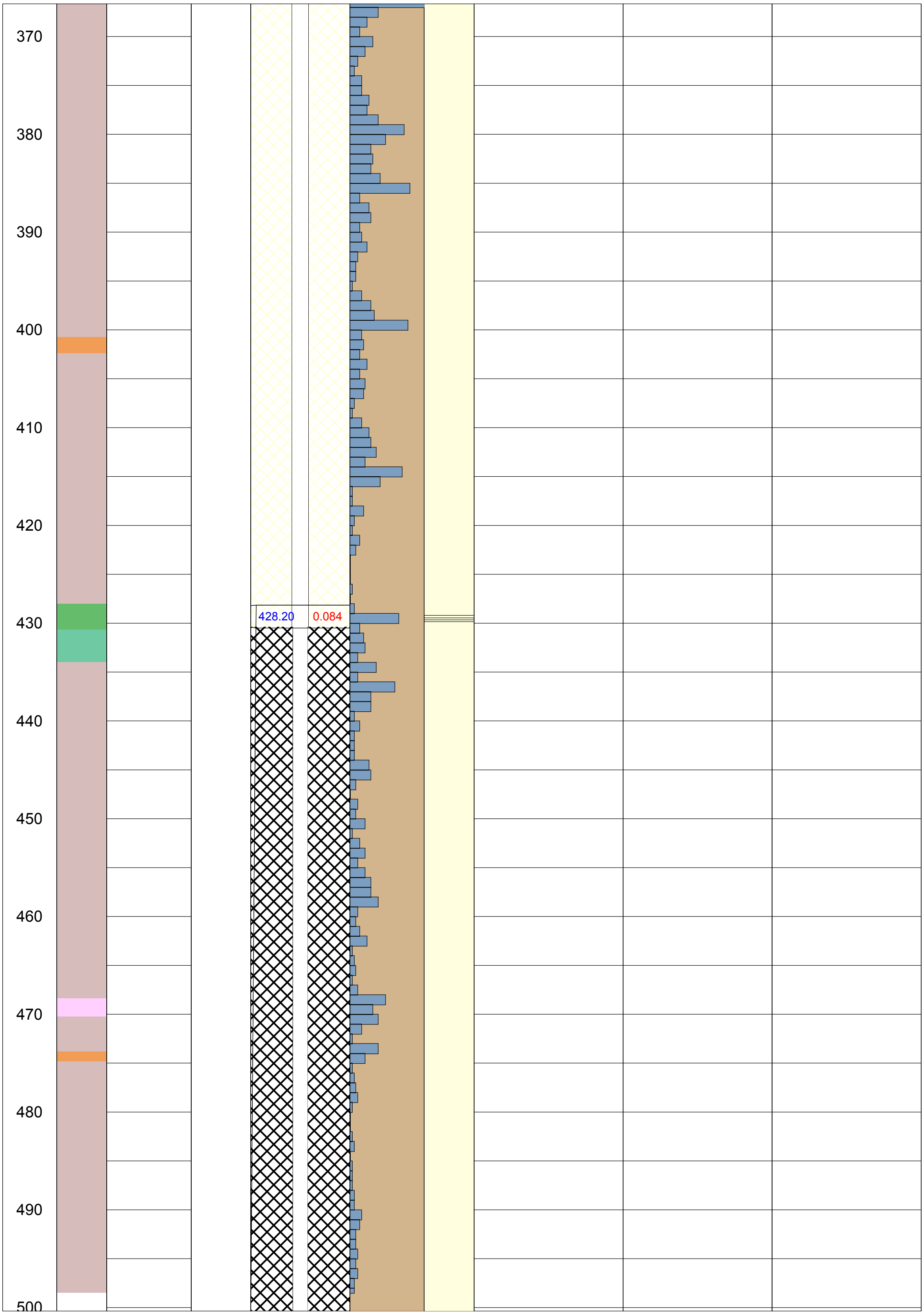
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